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by A. Aarkrog and J. Lippert

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INIS Descriptors

[0] DENMARK
ENVIRONMENT
RADIOACTIVITY
RADIOECOLOGICAL CONCENTRATION

[1] AIR
BONE TISSUES
FRESH WATER
GROUND WATER
RAIN WATER
STRONTIUM 90

[1, 2] BACKGROUND RADIATION
DIET
FOOD
FOOD CHAINS
GAMMA RADIATION
GLOBAL FALLOUT
PLANTS
SEAWATER

[2] WHOLE-BODY RADIATION

[2, 4] CESIUM 137

[1, 2, 3] SOILS

[3] CEREALS
PLUTONIUM 239
PLUTONIUM 240
SEEDS

[3, 4] SEDIMENTS

[4] CORROSION PRODUCTS
FUCUS
MOLLUSCS
NUCLEAR POWER PLANTS

UDC 614.73 (489)

Environmental Radioactivity in Denmark in 1976

by

A. Aarkrog and J. Lippert

Risø National Laboratory
Health Physics Department

Abstract

The present report deals with the measurement of fall-out radioactivity in Denmark in 1976. Strontium-90 was determined in samples from all over the country of precipitation, soil, ground water, sea water, grass, dried milk, fresh milk, grain, bread, potatoes, vegetables, fruit, total diet, and human bone. Furthermore, ^{90}Sr was determined in local samples of air, rain water, grass, sea plants, fish, and meat. Caesium-137 was determined in soil, sea water, milk, grain products, potatoes, vegetables, fruit, total diet, fish, and meat. It was also measured by wholebody-counting of a control group at Risø. Estimates of the mean contents of radiostrontium and radiocaesium in the human diet in Denmark during 1976 are given. The γ-background was measured regularly at locations around Risø, and ten of the State experimental farms. The marine environments at Barsebäck and Ringhals were monitored for ^{137}Cs and corrosion products. Finally the report includes routine surveys of environmental samples from the Risø area. Results of plutonium determinations in soil and sediments from 1975 and in grain from 1963 and 1965 are presented in this report.

Stougaard Jensen/København

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CONTENTS

ABBREVIATIONS AND UNITS

FP	fission products
fCi	femtocurie 10^{-15} Ci
pCi	picocurie, 10^{-12} Ci, μμCi
nCi	nanocurie, 10^{-9} Ci, mμCi
mCi	millicurie, 10^{-3} Ci
MPC	maximum permissible concentration
c/min	counts per minute
d/min	disintegrations per minute
c/h	counts per hour
μR	micro-roentgen, 10^{-6} roentgen
S.U.	pCi ^{90}Sr/g Ca
O.R.	observed ratio
M.U.	pCi ^{137}Cs/g K
V	vertebrae
m	male
f	female
nSr	natural (stable) Sr
eqv. μgU	equivalents μg uranium: activity as from 1 μg U (∿90 d/h)
eqv. mg KCl	equivalents mg KCl: activity as from 1 mg KCl (∿0.88 d/min)
S.D.	standard deviation: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{(n-1)}}$
S.E.	standard error: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n(n-1)}}$
U.C.L.	upper control level
L.C.L.	lower control level
Δ	one standard deviation due to counting
S.S.D.	sum of squares of deviation: $\Sigma(\bar{x}-x_i)^2$
f	degrees of freedom
s^2	variance

Samples:

H:	sea water
J:	soil
L:	air
B:	bed soil
Å:	eel
PG:	grass
PH:	sea plants
D:	drain water
S:	waste water
R:	precipitation
M:	milk

v^2	ratio between the variance in question and the residual variance
P	probability fractile of the distribution in question
η	coefficient of variation, relative standard deviation
annova	analysis of variance
A	relative standard deviation 20-33%
B	relative standard deviation > 33%, such results are not considered significantly different from zero activity
B.D.L.	below detection limit

In the significance test the following symbols were used:

* : probably significant (P > 95%),

** : significant (P > 99%).

***: highly significant (P > 99.9%)

1. INTRODUCTION

1.1.

The present report is the twentieth of a series of periodic reports (cf. ref. 1) dealing with measurements of radioactivity in Denmark. The programme is unchanged as compared with 1975, but some samples (dried milk, grain, bread, vegetables and fruit) have due to low levels been pooled before analysis.

1.2.

The methods of radiochemical analysis[2-4] and the statistical treatment of the results[5] are still based on the principles established in previous reports[1].

1.3.

The report does not include detailed tables of the total β-measurements from the environmental control of the Risø site. These tables are available in the form of microcards at the Risø library.

1.4.

The report contains no information on sample collection and analysis except in the cases where these procedures have been altered.

1.5.

In 1976 the personnel of the Environmental Control Section of the Health Physics Department consisted of one chemist, ten laboratory technicians, two sample collecters, and two laboratory assistants. The Section for Electronics Development continued to give assistance in the maintenance of the counting equipment and in the interpretation of the γ-spectra. The program (cf. 2) used in the calculations of ^{90}Sr and the γ-analysis, as well as the program for data treatment, were developed by this section.

1.6.

The composition of the average Danish diet used in this report is identical with that proposed in 1962 by Professor E. Hoff-Jørgensen, Ph.D.

2. ORGANIZATION AND FACILITIES[1,6,7,8]

Four Ge-(Li)-detectors and an 8 inch NaI(TL)-detector used for whole-body measurements each connected to a 1024-channel analyzer are available. Eight detectors for alpha spectrometry are connected to two 256-channel analyzers.

A computer program, STATDATA[16], is available for the treatment of the results of this report (and the results of several other projects). The program checks and stores the data, produses lists, tables and plots and calls separate programs for analysis of variance and regression, etc. The principle for registering the data is the assignment of 6 parameters to each result or set of mulitple results. These parameters are:

Isotope (or code for γ-background, etc.)
Sampling date
Sample type
Sampling location
Quality of measurement (relative standard deviation)
Unit of results

followed by:

Number of results
Results.

Routines for treatment of γ-spectra and for calculations on empirical prediction models (app. C) has been included in programme.

To date approximately 40000 sets of results have been registered covering the period from 1957. However, a number of results still remains unregistered.

3. ENVIRONMENTAL MONITORING AT RISØ IN 1976

3.1. Gross β-Activity

3.1.1. Sea Water

Fig. 3.1.1.1 shows the sample locations in Roskilde Fjord. Fig. 3.1.1.2 shows the control chart for H I. The yearly mean for H I in 1976 was 58 eqv. mg KCl/2.5 g (in 1975: 56), for H III-VI: 55 eqv. mg KCl/2.5 g (in 1975: 53) and for H VII-X: 55 eqv. mg KCl/2.5 g (in 1975: 54). Fig. 3.1.1.3 shows the mean levels of radioactivity in sea salt since 1957.

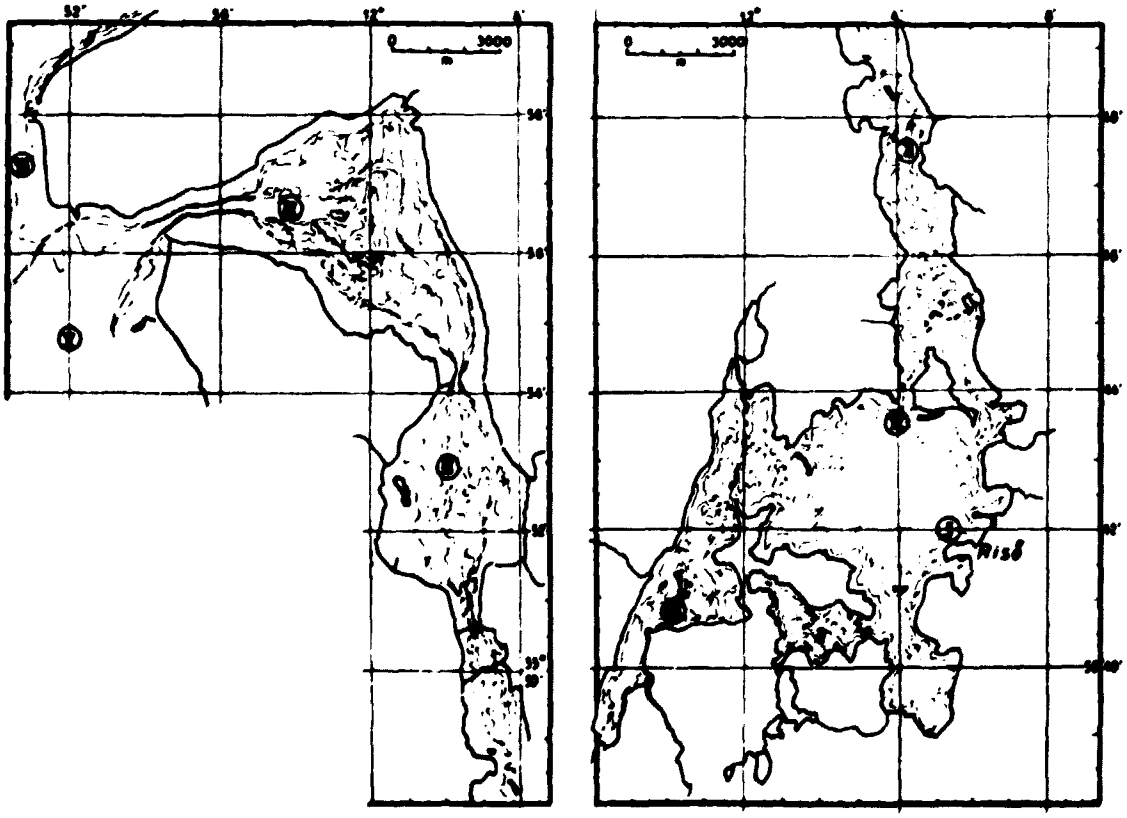

Fig. 3.1.1.1. Roskilde Fjord.

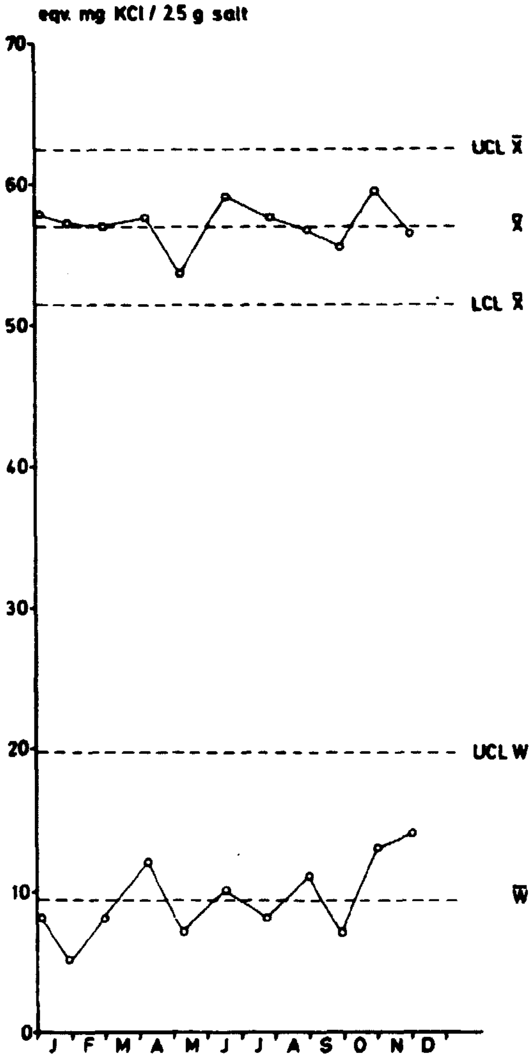

Fig. 3.1.1.2. Control chart for HI, 1976.

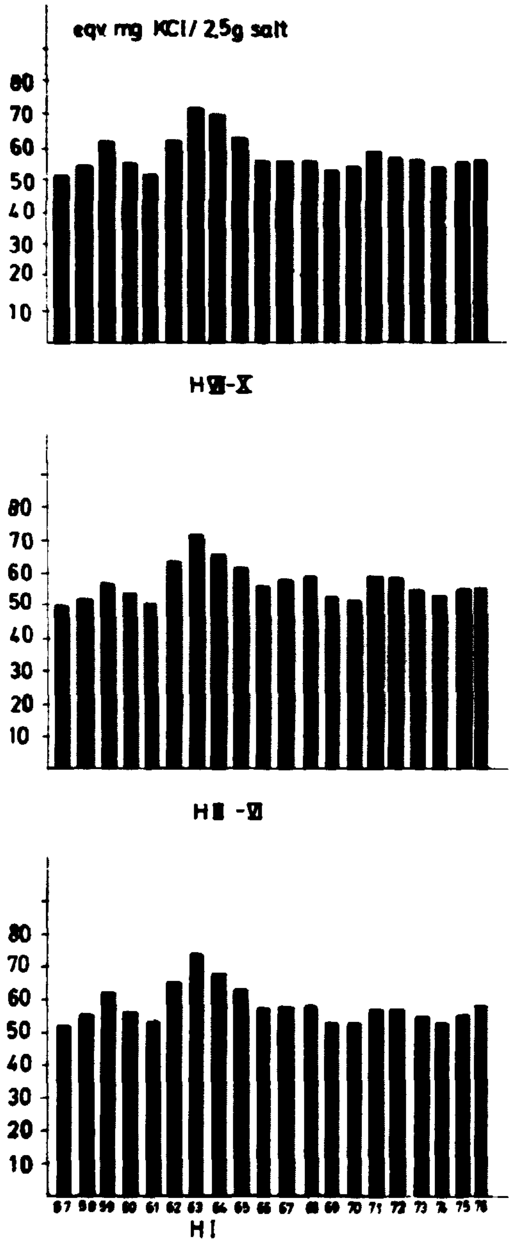

Fig. 3.1.1.3. Mean radioactivity in sea water 1957-76.

3.1.2. Soil

No soil samples from the environment of Risø were measured for total β-activity in 1976.

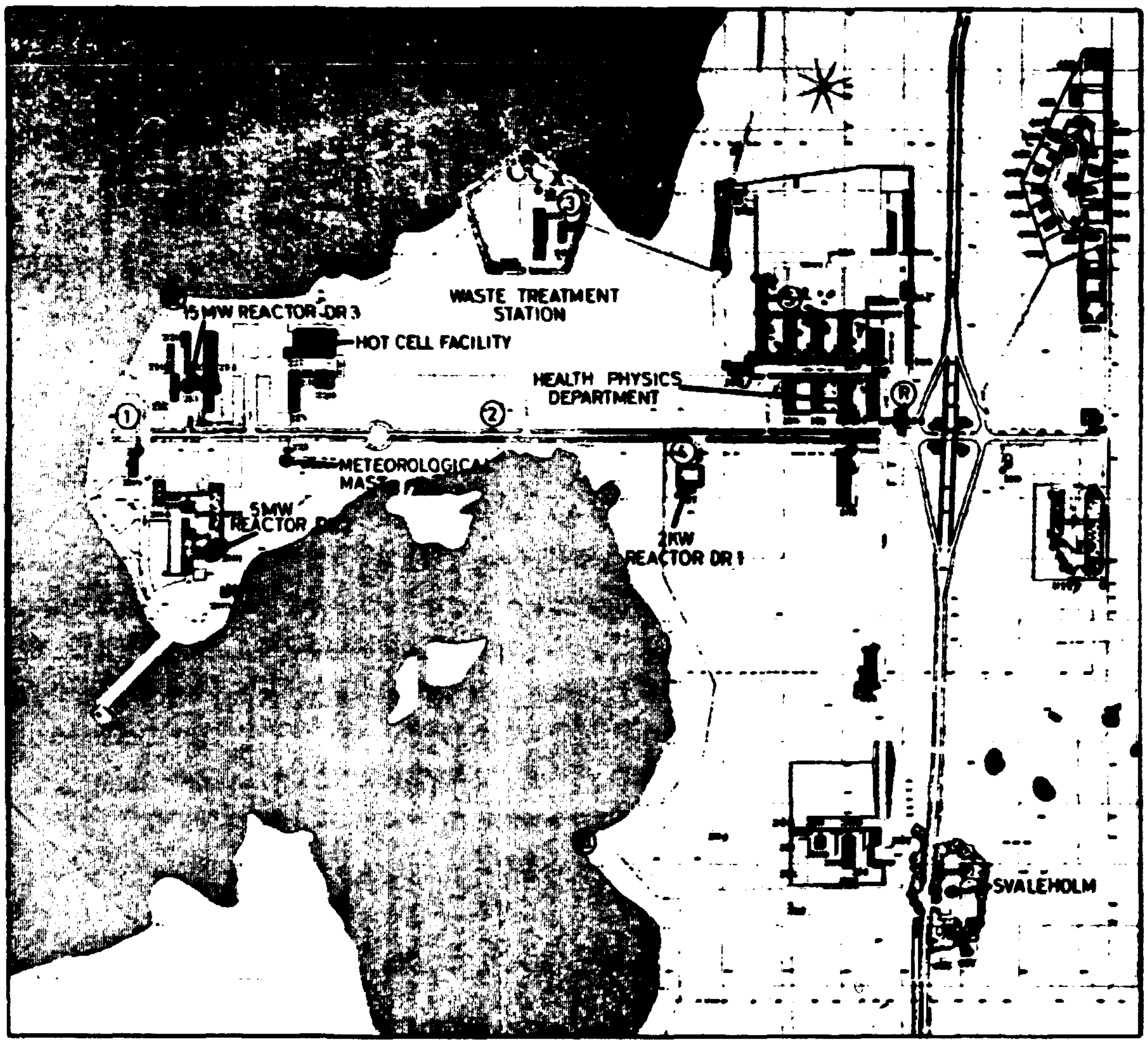

Fig. 3.1.2.1. Risø National Laboratory.

3.1.3. Air

Fig. 3.1.3.1 shows the diagram for FP activity in air samples in 1976. The mean value for the year was 0.15 eqv. mg KCl/m^3 as compared with 0.18 eqv. mg KCl/m^3 in 1975.

Fig. 3.1.3.2 shows the mean FP levels in air since 1957.

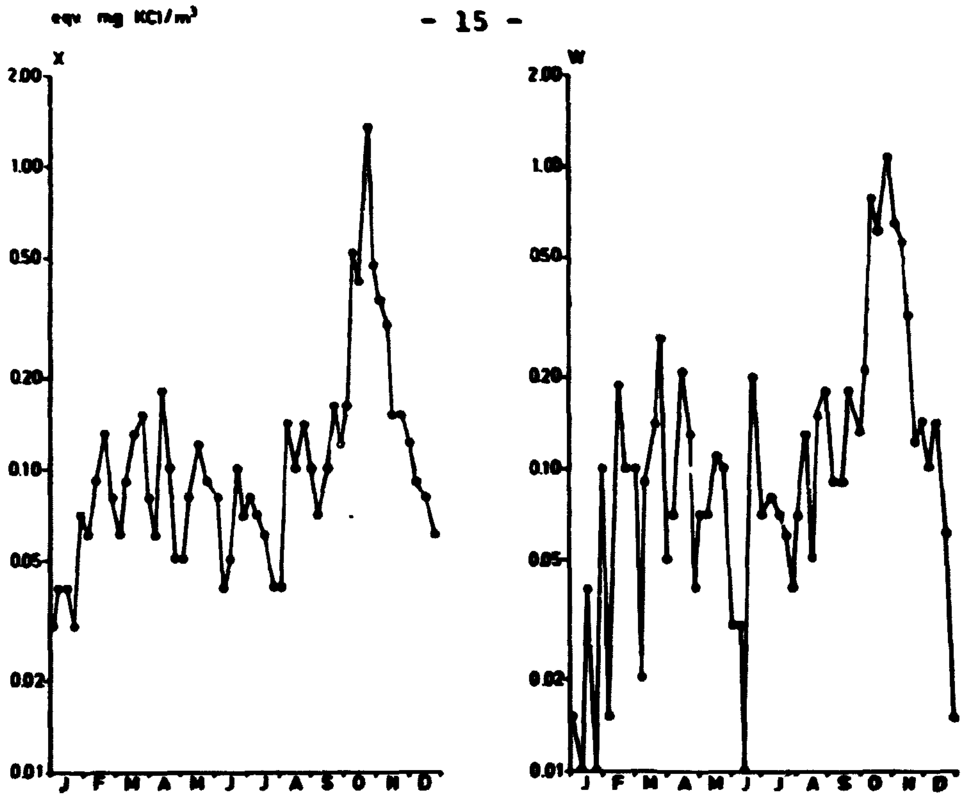

Fig. 3.1.3.1. Control chart for LF, 1976.

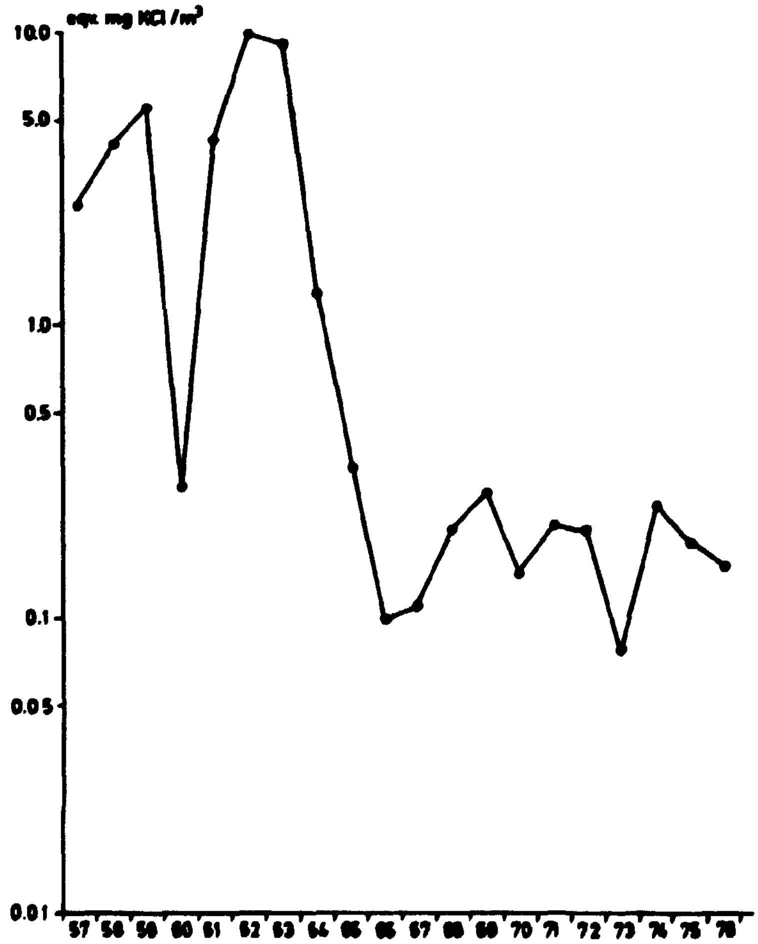

Fig. 3.1.3.2. Mean radioactivity in air, 1957-76.

3.1.4. Bed Soil from the Fjord

The mean activity in bed soil B I was 136.5 eqv. mg KCl/ 3.0 g ash in 1976 as compared with 143 eqv. mg KCl/3.0 g in 1975. Fig. 3.1.4.1 shows the mean levels for B I since 1957 (cf. also 3.4).

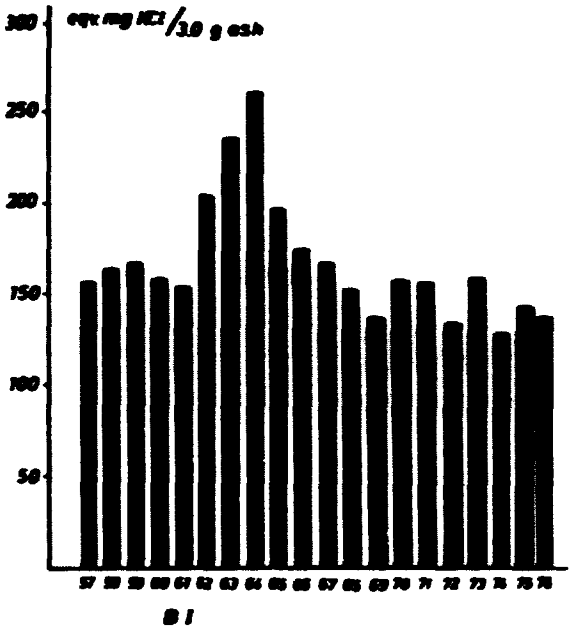

Fig. 3.1.4.1. Mean radioactivity in bed soil, 1957-76.

3.1.5. Fish

No fish samples from Roskilde Fjord were measured for total β-activity in 1976.

3.1.6. Grass

The mean values were in 1976 for PG I: 15 eqv. mg KCl/0.1 g grass ash (in 1975: 14), for PG II-III: 20 eqv. mg KCl/0.1 g (in 1975: 11) and for PG IV-V: 10 eqv. mg KCl/0.1 g (in 1975: 7). Fig. 3.1.6.1 shows the mean activities in grass ash since 1957.

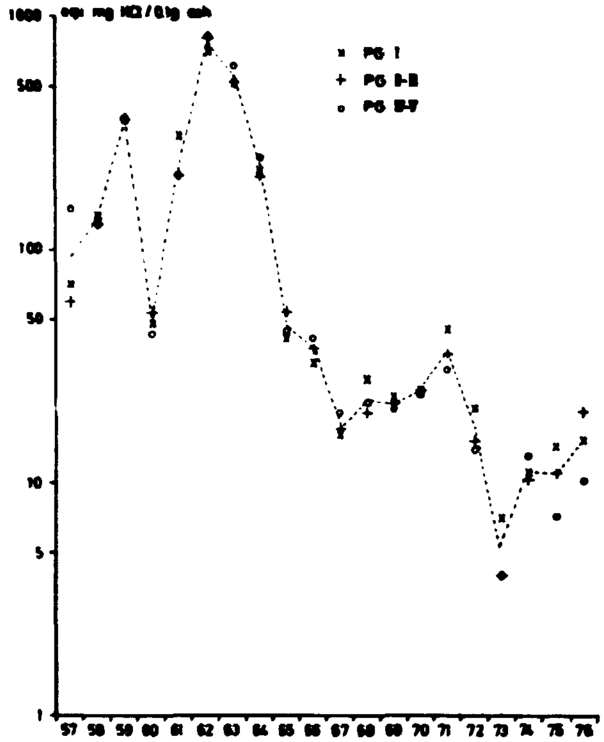

Fig. 3.1.6.1. Mean FP-radioactivity in grass ash, 1967-76.

3.1.7. Sea Plants

The mean FP level in 1976 in Fucus vesicolosus (PH I) was 2 eqv. mg KCl/0.1 g ash (2 in 1975). In Zostera marina (PH III-IX) we found 2 eqv. mg KCl/0.1 g ash in 1976 (1 in 1975).

3.1.8. Fresh Water

Fig. 3.1.8.1 shows the control chart for S (cf. fig.3.1.2.1). The yearly means for D I, D II, D IV, and S in 1976 were 17 eqv. mg KCl/l (1975: 18), 19 eqv. mg KCl/l (1975: 14), 42 eqv. mg KCl/l (1975: 55), and 46 eqv. mg KCl/l (1975: 35) respectively. Fig. 3.1.8.2 shows the activity in drainage water (D) and sewage water (S).

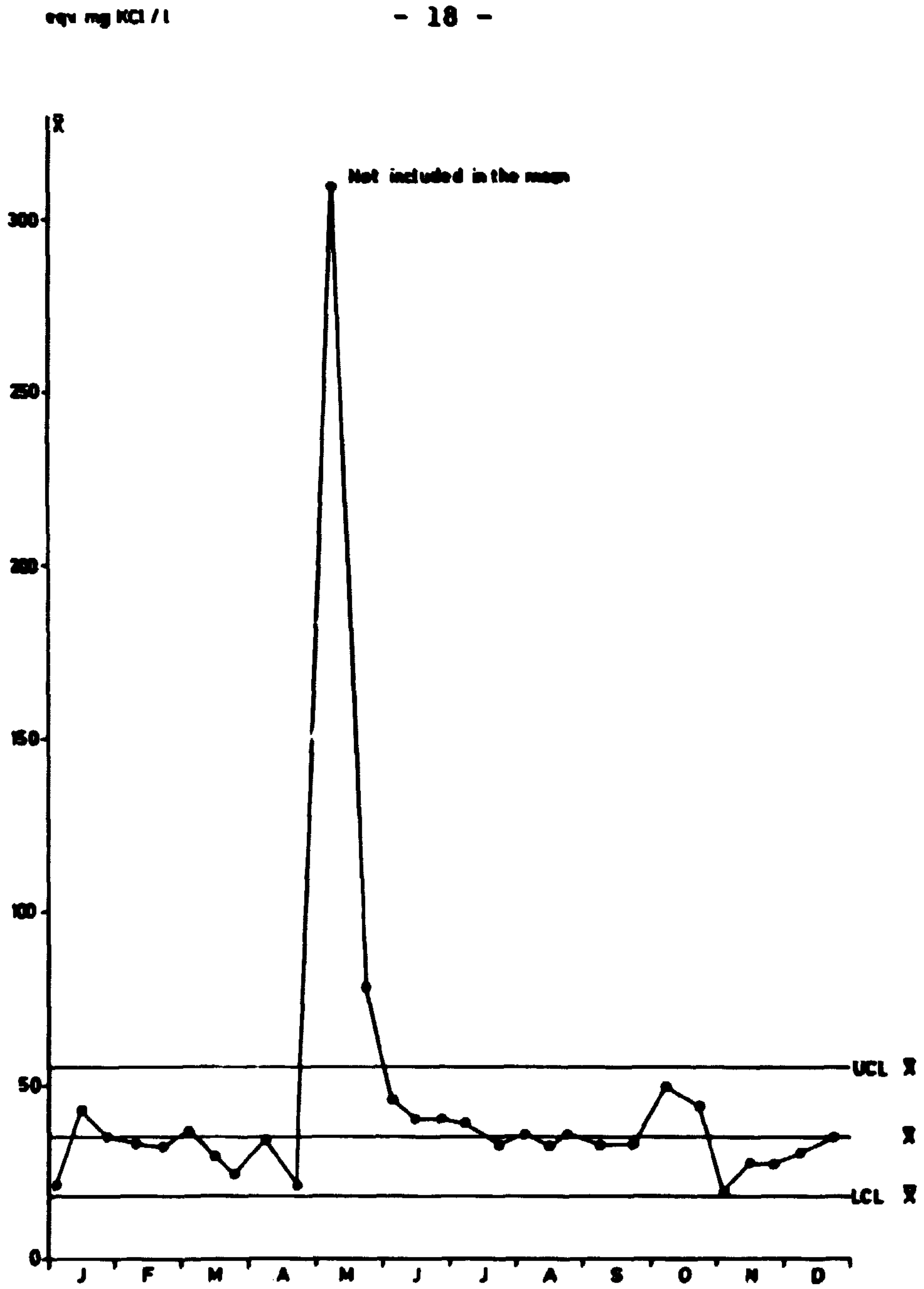

Fig. 3.1.8.1. Control chart for sewage water (S) 1976.

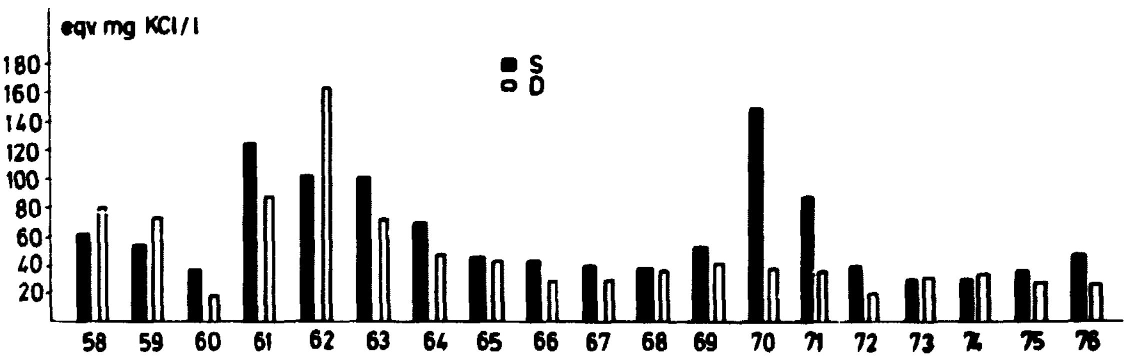

Fig. 3.1.8.2. Mean radioactivity in 1976.

3.1.9. Rain Water

Figs. 3.1.9.1 and 3.1.9.2 show the specific FP level in and the total fall-out from rain water collected daily at Risø in 1 m^2 rain collector in 1976. The total fall-out in 1976 was measured at $0.014 \cdot 10^6$ eqv. mg KCl/m^2, and the annual mean concentration in rain water at Risø was 42 eqv. mg KCl/l. In 1975 the corresponding figures were $0.008 \cdot 10^6$ and 18 respectively.

Fig. 3.1.9.3 shows the specific activity in rain water since 1957.

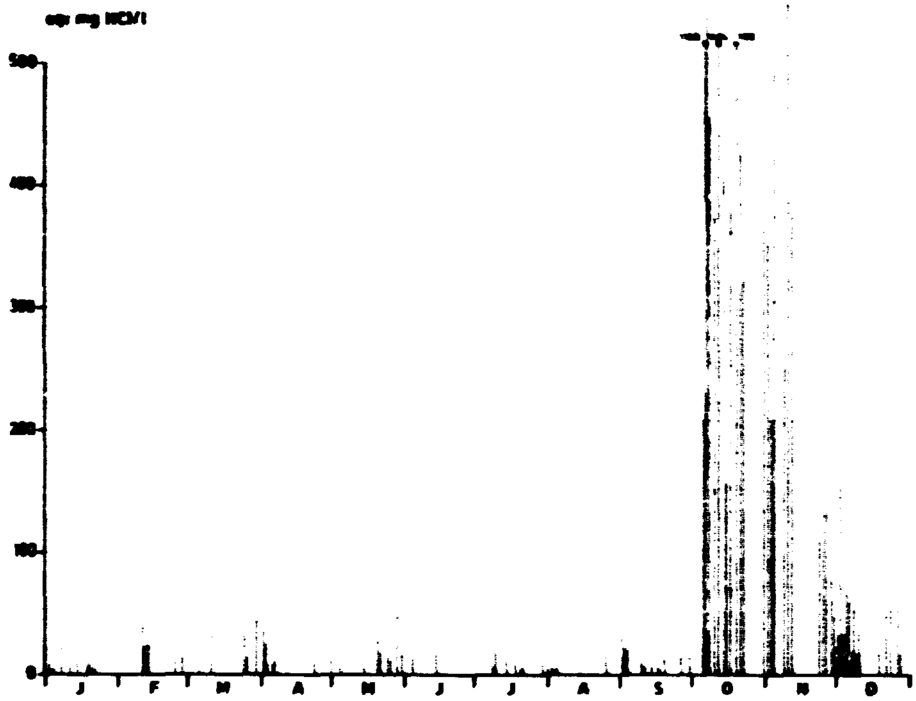

Fig. 3.1.9.1. Concentration of β-activity in precipitation in 1976.

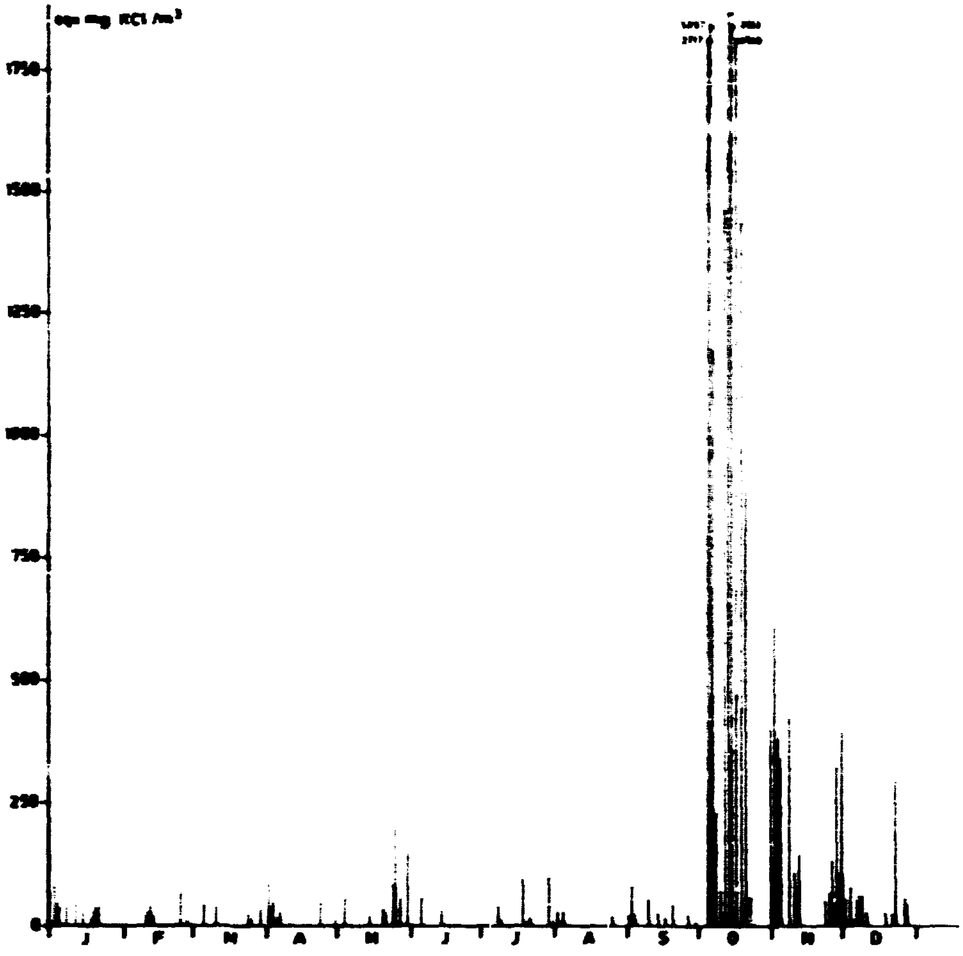

Fig. 3.1.9.2. Total fall-out from precipitation in 1976.

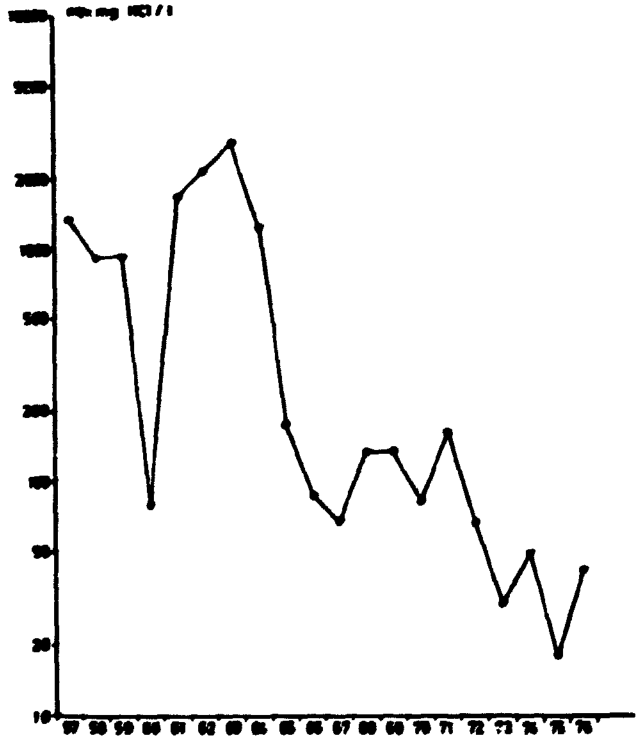

Fig. 3.1.9.3. Specific activity in precipitation, 1957-76.

3.2. Radiochemical β-Analysis

3.2.1. Air

The "big air sampler" described in Risø Report No. 23[1] has a shunt through which the air volume is determined. As in previous years, both the shunt filter (I) and aliquots cut out of the main filter (II) were analysed to see whether activity levels were identical in the two filters. As I/II = 1.14 $\pm$ 0.08 (1 SE), we still concluded that the two filters showed the same levels. The mean air activity level for 1976 is reported as the mean of the glass-fibre filter collection and the daily paper filter sampling: 0.21 $\pm$ 0.07 pCi $^{90}Sr/10^3$ m^3, i.e. a quarter of the 1975 level. The mean peak activity of the three collections in 1976 was measured in June at 0.39 pCi $^{90}Sr/10^3$ m^3.

Fig. 3.2.1.1 shows the ^{90}Sr levels in air since 1957.

Table 3.2.1.2 shows the presence of fresh fall-out from a Chinese atmospheric explosion on 26 September 1977. The corrected ratios indicate a $^{89}Sr/^{90}Sr$ at formation in the range of 145-185, i.e. equal to the expected value.

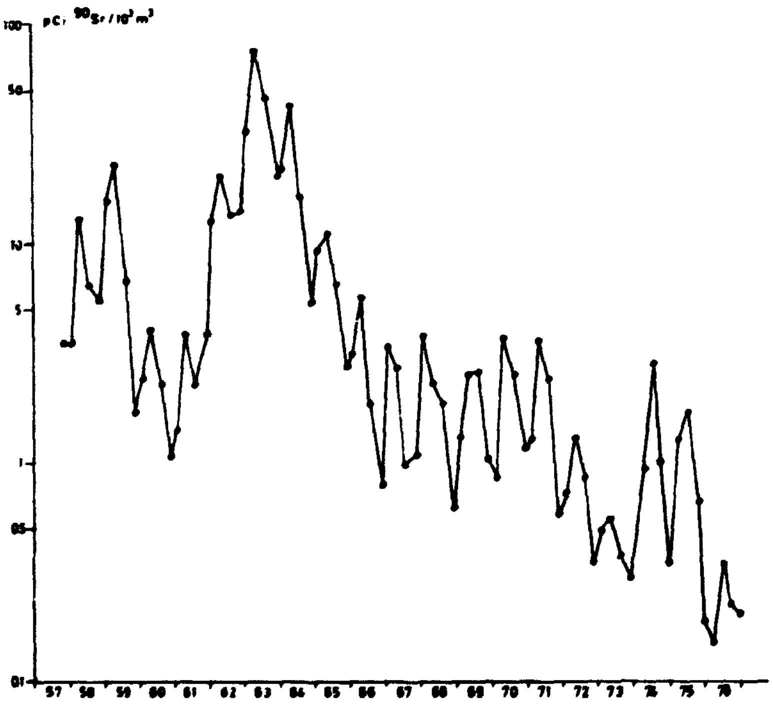

Fig. 3.2.1.1. Quarterly ^{90}Sr levels in air, 1957-76.

Table 3.2.1.1

Strontium-90 in air collected at Risø in 1976
pCi ^{90}Sr $10^{-3}m^{-3}$

Month	Daily air filters	Monthly air filters (glass-fibre filters)	
	Paper	I	II
Jan	0.165	0.102	0.083
Feb	0.205	0.162	0.122
March	0.193	0.223	0.125
April	0.189	0.180	0.173
May	0.297	0.377	0.359
June	0.318	0.417	0.423
July	0.250	0.416	0.344
Aug	0.197	0.275	0.198
Sept	0.122	0.099 A	0.110
Oct	0.204	0.158	0.158
Nov	0.194	0.188	0.184 A
Dec	0.124	0.090	0.129
1976	0.205	0.224	0.201

I: the normally used shunt filters.

II: aliquots cut out of the main filters also used for ^{137}Cs determination (cf. table 3.3.1).

Table 3.2.1.2

Ratio $^{89}Sr/^{90}Sr$ in air collected at Risø in 1976

Month	Daily paper air filters	Ratios corrected for old ^{90}Sr*
Oct	70	100
Nov	49	72
Dec	29	57

*The old ^{90}Sr in Oct-Dec 1976 was empirically estimated to 50% of the Sept level. This was the ratio observed in 1975.

3.2.2. Grass

Table 3.2.2 shows the ^{90}Sr content in grass ash from Zealand in 1976. The mean ^{90}Sr activity was 1.6 pCi ^{90}Sr/g ash or 25 S.U. as compared with 2.6 pCi/g ash or 44 S.U. in 1975, i.e. the 1976 level was 0.6 times the 1975 level. Fig. 3.2.2.1 shows the ^{90}Sr concentration in grass since 1957 and fig. 3.2.2.2 shows the predicted levels (cf. Appendix C) compared with the measured.

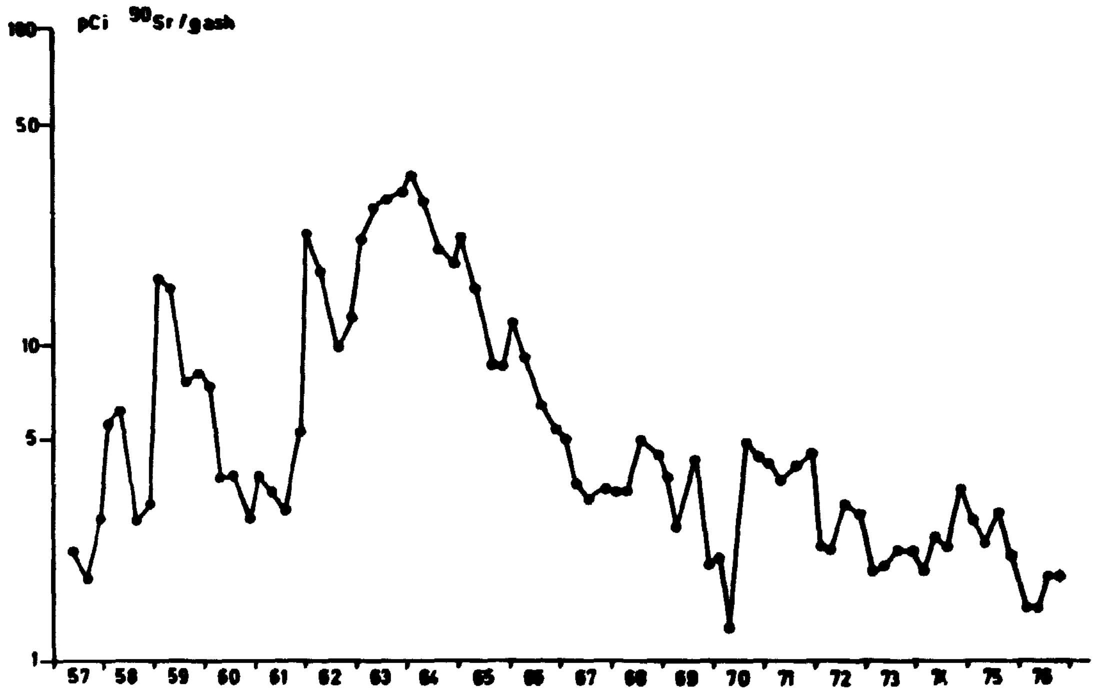

Fig. 3.2.2.1. Quarterly ^{90}Sr levels in grass, 1957-76.

Table 3.2.2

Strontium-90 in grass from Zealand, 1976

	pCi ^{90}Sr (g ash)$^{-1}$	pCi ^{90}Sr (g Ca)$^{-1}$
Jan-March	1.46	21.4
April-June	1.46	26.6
July-Sept	1.83	25.9
Oct-Dec	1.83	25.2
Mean	1.64	24.8

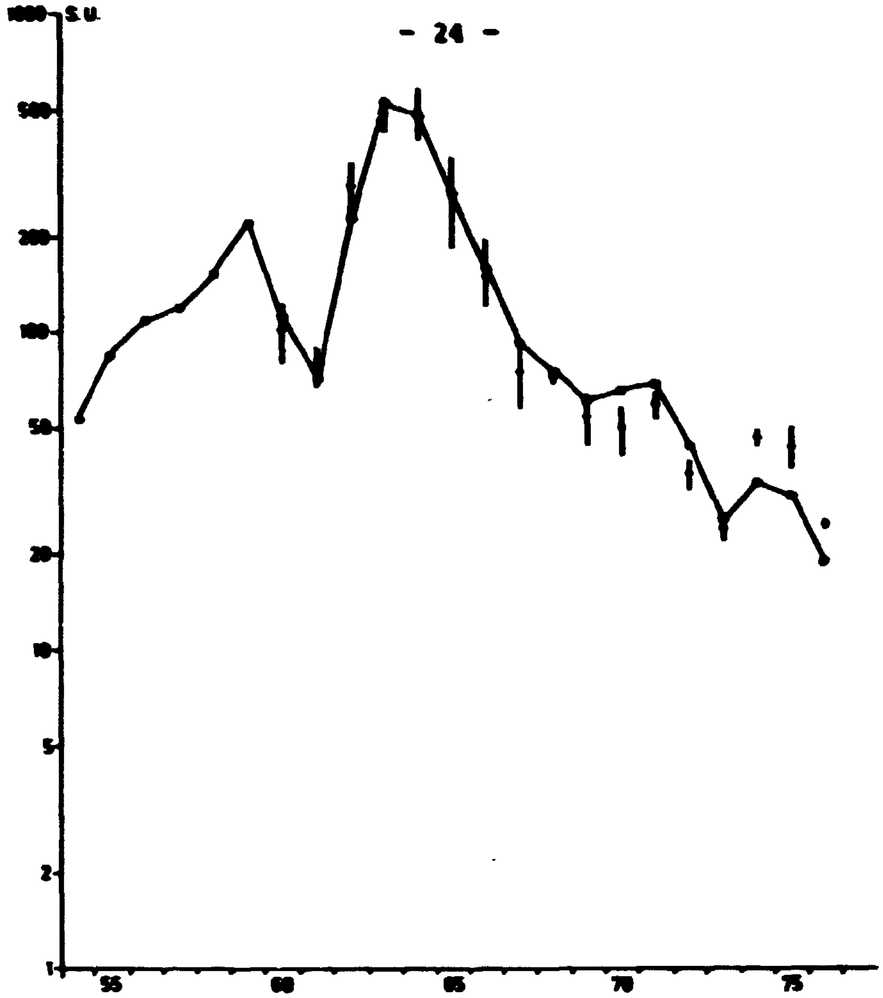

Fig. 3.2.2.2. A comparison between observed (± 1 S.E.) and calculated (curve, cf. appendix C) S.U. levels in grass from Zealand.

3.2.3. Sea Plants

Fig. 3.2.3 shows the S.U. levels in sea plants since 1959 and table 3.2.3 the results for 1976. The level in Fucus vesicolosus was 22.5 pCi ^{90}Sr/g Ca, and in Zostera marina 2.5 pCi ^{90}Sr/g Ca.

Table 3.2.3

Strontium-90 in sea plants from Roskilde Fjord in 1976

Month	Location	Species	pCi ^{90}Sr (g Ca)$^{-1}$	pCi ^{90}Sr (g ash)$^{-1}$
July	I	Fucus vesicolosus	10.2	0.72
Nov	I	Fucus vesicolosus	34.8	0.94
June	III	Zostera marina	2.4	0.26
Nov	III	Zostera marina	3.1	0.25
July	IX	Zostera marina	1.9	0.076

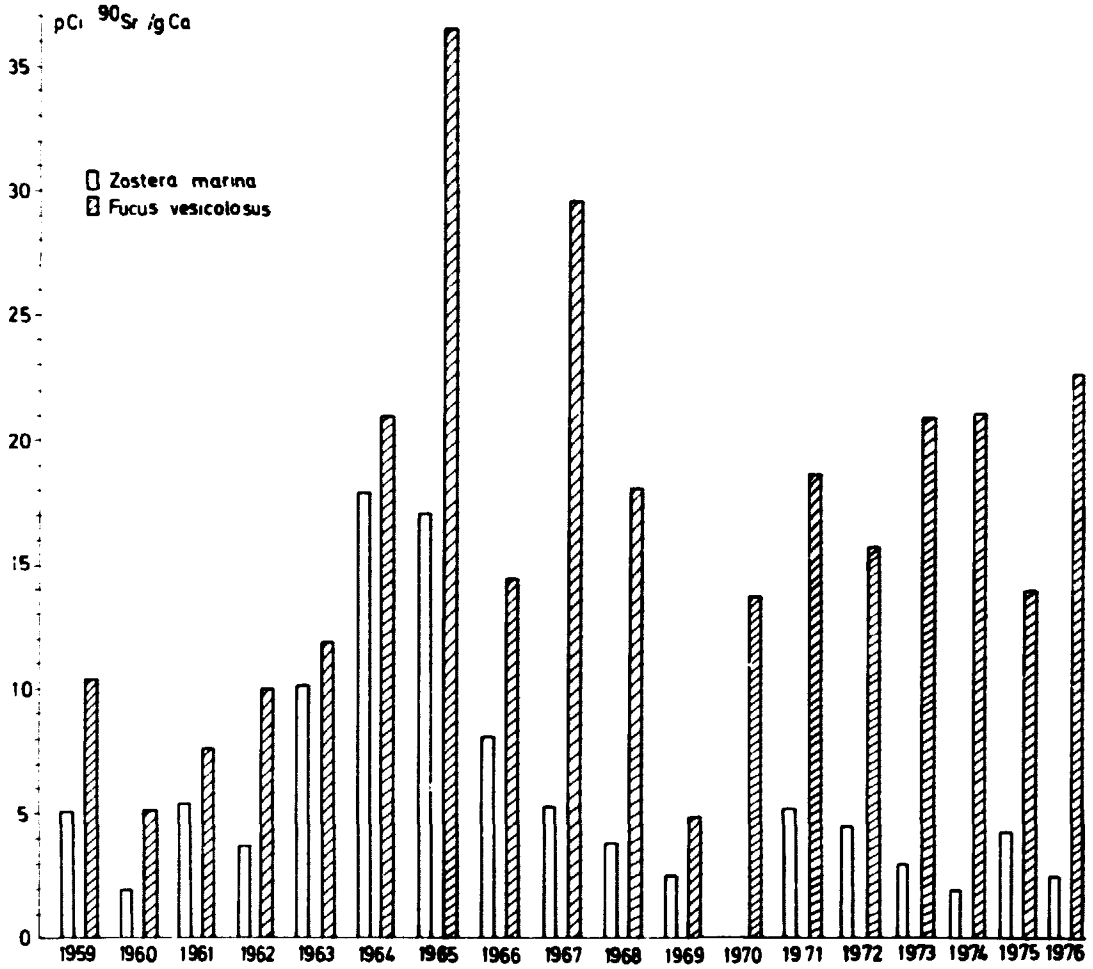

Fig. 3.2.3. Strontium-90 in sea plants from Roskilde Fjord, 1959-76.

3.2.4. Rain Water

Table 3.2.4.2 shows the quarterly radiostrontium levels in rain water collected in ion exchange columns at Risø in 1976. The total ^{90}Sr fall-out in 1976 was 0.04 mCi ^{90}Sr/km^2 (237 mm precipitation), and the mean concentration in the rain water was 0.17 pCi ^{90}Sr/l. In 1975 we measured 0.27 mCi ^{90}Sr/km^2 (477 mm precipitation) and 0.56 pCi ^{90}Sr/l, i.e. the 1976 ^{90}Sr concentrations were 0.3 times the 1975 figures. The deposition values in 1976 were probably too low due to incomplete sampling of the rain water; the precipitation measured by the ion exchange columns was thus nearly a factor of two too low in 1976.

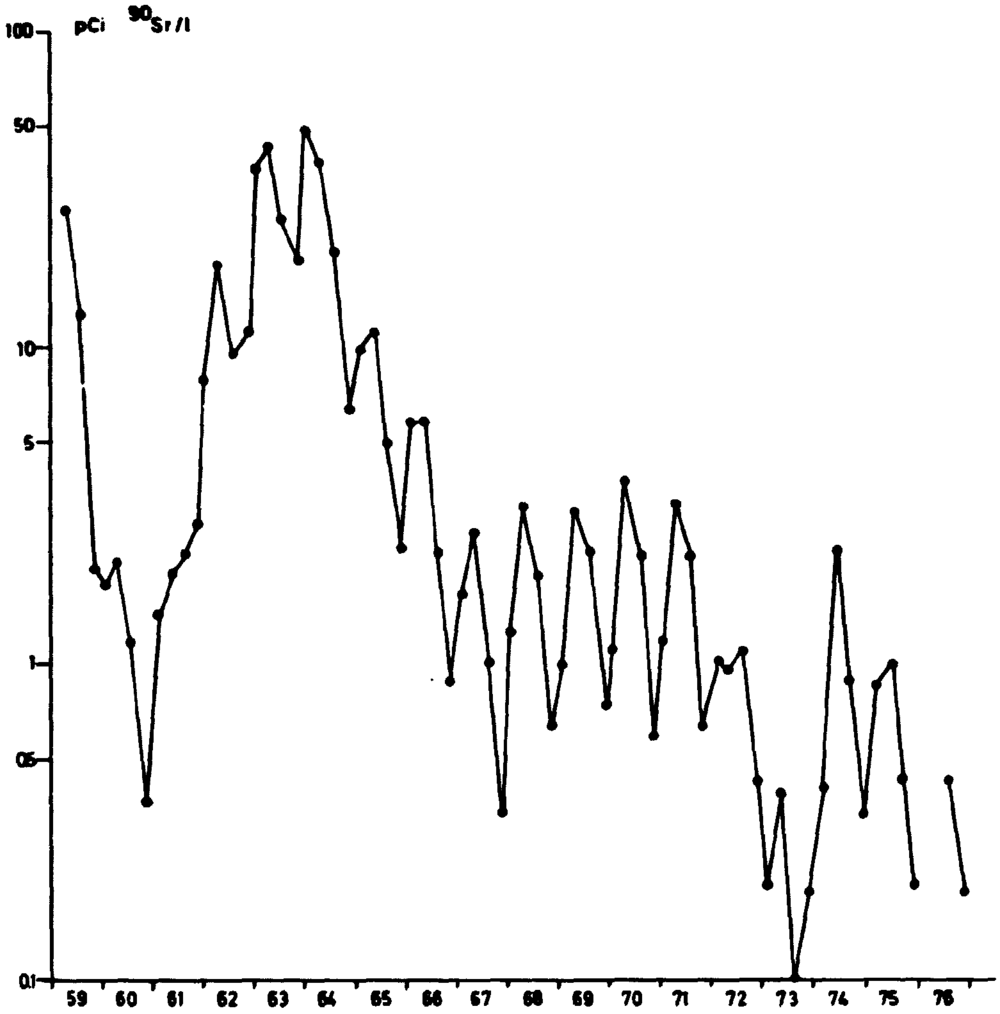

Fig. 3.2.4.1. Quarterly ^{90}Sr levels in precipitation, 1959-76.

Table 3.2.4.1

Strontim-90 in rain water collected in ion-exchange column collectors at Risø in 1976 (sampling area 0.325 m^2)

Month	mm	pCi ^{90}Sr l^{-1}	mCi ^{90}Sr km^{-2}	^{89}Sr/^{90}Sr
Jan-March	48	0.157	0.0075	
April-June	64	0.175	0.0111	
July-Sept	63	0.126	0.0080	32
Oct-Dec	62	0.224	0.0140	9.6 B
1976	Σ 237	$\bar{x}$ 0.171	Σ 0.0406	

3.2.5. Milk from a Farm near Risø

The Chinese test explosion on 26 September 1976 resulted in a temporary contamination of cows' milk by ^{131}I. The time-integrated level was approx. 200 pCi ^{131}I days, corresponding to a dose of 2 mrad to the infant thyroid[21].

Table 3.2.5

Iodine-131 in milk from Risø* in 1976

Date	pCi ^{131}I l^{-1}
Oct. 13	12.5
Oct. 15	5.9
Oct. 20	22.6±0.8
Oct. 22	22.8±0.8
Oct. 25	7.4

*The milk was obtained from the milk-producing farm nearest to Risø.

3.3. γ-Spectroscopy of Air, Precipitation and Grass Samples

As in 1962-1975, samples of air were collected twice a weak by means of the air sampler described in Risø Report No. 23[1]. The filters were measured on a 30 cm^3 Ge(Li) detector[8]. Table 3.3.1 shows the monthly means of the ^{137}Cs determinations. The peak value was observed in May. The mean level in 1976 was a third of the 1975 mean. The $^{137}Cs/^{90}Sr$ mean ratio in air filter was 2.1 in 1976.

Debris from the Chinese atmospheric nuclear test explosion on 26 September 1976 appeared in ground-level air collected at Risø ten days after the explosion. The short-lived nuclides were followed in air filters until the end of November (fig. 3.3.2). The mean ratios (corrected for decay to 26 September between short-lived radionuclides measured in air samples were compatible with those expected[4] (table 3.3.4). Some ratios, however, showed an evident time trend: $^{131}I/^{140}Ba$, $^{141}Ce/^{103}Ru$ and $^{95}Zr/^{103}Ru$ thus decreased with time, while $^{140}Ba/^{95}Zr$ and $^{141}Ce/^{95}Zr$ increased. This may indicate that the fresh fall-out from the explosion was enriched in ^{95}Zr and depleted in ^{140}Ba

Table 3.3.1

Caesium-137 in glass-fibre air filters collected twice a week at Risø in 1976

Month	pCi $^{137}Cs/10^3 m^3$
Jan.	0.25±0.04
Feb.	0.33±0.03
March	0.34±0.03
April	0.41±0.06
May	0.64±0.06
June	0.61±0.05
July	0.56±0.10
Aug.	0.42±0.03
Sept.	0.27±0.04
Oct	0.48±0.14
Nov	0.47±0.08
Dec	0.25±0.03
1976	0.42

The error term is the S.E. of the mean of the activity found in 8 or 9 filters collected during a month.

Table 3.3.2

(unit fCi m^{-3})

Short-lived nuclides in ground-level air samples collected at Risø in 1976
Activity referred to the middle of the sampling period

Nuclide	Collected Oct 4-Oct 7	Collected Oct 7-Oct 11	Collected Oct 11-Oct 14	Collected Oct 14-Oct 18	Collected Oct 18-Oct 21
^{144}Ce	-	7.0	8.7	3.7	6.1
^{141}Ce	4.0	29	40	9.4	15
^{237}U	1.0	2.7	2.1	-	-
^{239}Np	19	56	27	-	-
^{140}La	11±1	60±7	98±12	18±2	26±3
^{131}I	8.6	25	30	6.8	8.8
^{7}Be	100	130	78	50	105
^{103}Ru	2.8	10	29	6.2	8.5
^{106}Ru	1.2	5.6	6.2	2.6	2.1
^{140}Ba	8.7	43	75	14	21
^{132}I	5.2±0.5	15.3±0.2	13±1	1.9±0.1	-
^{95}Zr	2.9	20±2	40±4	8.6±1	15±2
^{95}Nb	0.9	6.0	3.5	3.4	6.6

Table 3.3.3

Short-lived radionuclides in precipitation samples collected at Risø in 1976 (activity at time of collection)

	Collected Oct 5-7		Collected Oct 15		Collected Oct 17	
	pCi l^{-1}	pCi m^{-2}	pCi l^{-1}	pCi m^{-2}	pCi l^{-1}	pCi m^{-2}
^{144}Ce	-	-	2.0	38	-	-
^{141}Ce	2.4	47	3.2	61	9.4	110
^{140}La	14±1	280±20	15±2	290±40	41±5	490±60
^{131}I	37	730	11	210	21	250
^{7}Be	15	300	17	320	47	560
^{103}Ru	8.8	170	9.8	190	11	130
^{106}Ru	2.7	55	3.8	73	5.7	68
^{140}Ba	22	430	18	340	41	500
^{95}Zr	3.5±0.1	70±2	4.1±0.4	78±8	5.7±1.3	69±15
^{95}Nb	0.8	15	1.3	25	3.0	36

The samples were collected by means of a 1 m^2 rain collector (3.1.9), and before Ge-γ-spectroscopy the rain water was ion-exchanged on a mixed-bed Dowex-column in the laboratory.

Table 3.3.4

Radionuclide ratios in air and rain samples collected at Risø in Oct and Nov 1976

Sample	Period of sampling	Nuclide ratio	Mean ratio ±1 S.E. on Sept 26, 1976 (I)	Theoretical ratio at formation[4] (II)	t-test between (I) & (II): t	df.	sign
Air	Oct 4-Nov 27	$^{131}I/^{140}Ba$	1.04±0.09	0.89	1.59	15	-
Rain	Oct 5-Oct 17		1.3 ±0.2		1.97	2	-
Air	Oct 4-Nov 27	$^{131}I/^{141}Ce$	2.9 ±0.2	2.59	1.61	15	-
Rain	Oct 15-Oct 17		18 ±7		2.25	2	-
Air	Oct 4-Nov 27	$^{131}I/^{95}Zr$	5.5 ±0.6	4.6	1.55	15	-
Rain	Oct 5-Oct 17		18 ±3		4.12	2	-
Air	Oct 4-Nov 27	$^{140}Ba/^{95}Zr$	5.9 ±0.9	5.2	1.23	15	-
Rain	Oct 5-Nov 30		13 ±2		2.83	3	-
Air	Oct 4-Nov 27	$^{141}Ce/^{103}Ru$	1.37±0.14	1.05	2.26	15	*
Rain	Oct 5-Nov 30		0.58±0.15		3.09	3	-
Air	Oct 4-Nov 27	$^{141}Ce/^{95}Zr$	1.9 ±0.1	1.77	0.84	15	-
Rain	Oct 5-Nov 30		0.55±0.14		8.48	3	**
Air	Oct 4-Nov 27	$^{95}Zr/^{103}Ru$	0.85±0.11	0.60	2.20	14	*
Rain	Oct 5-Nov 30		0.66±0.16		0.35	3	-

Table 3.3.5

Washout factors in fresh debris ($W_o = \frac{pCi\ l^{-1}\ (rain)}{fCi\ m^{-3}\ (air)}$)

Date \ Nuclide	^{95}Zr	^{95}Nb	^{103}Ru	^{140}Ba	^{140}La	^{141}Ce	^{131}I	$\bar{x}$	S.D.	S.E.
Oct 4-7	1.22	0.87	1.1	2.5	1.32	0.60	4.3	1.99	1.36	0.51
Oct 14-18	0.57	0.63	1.7	2.1	1.58	0.67	2.4	1.38	0.76	0.29
Nov 1976	1.57	1.48	1.00	1.55	1.76	0.97	*)	1.32	0.33	0.13

The radionuclide concentrations in rain were determined by ion exchange; the October samples in the laboratory on precipitation collected in the 1 m^2 rain sampler at Risø (3.1.9) and the November sample on the monthly collection of fallout in the five ion-exchange collectors at Risø (3.2.4).

*) too low a concentration for reliable determination.

Table 3.3.6

pCi m^{-2} in grass from Risø in Oct-Nov 1976

Date 1976	Oct 12	Oct 15*	Oct 15	Oct 18*	Oct 21	Oct 25*	Nov 1*	Nov 8	Nov 15
g fresh weight m^{-2}	260	257	174	200	174	319	353	397	230
g dry weight m^{-2}	36	43	66	41	66	44	49	61	33
mm precipitation since last sampling	-	6	6	31	1.3	2.3	1.1	4.4	2.3
^{95}Zr	220	406	795	365	810	469	415	473	154
^{95}Nb	82	144	291	130	323	215	227	310	103
^{103}Ru	39	70	228	95	157	109	129	118	48
^{131}I	172	235	457	196	264	132	79	60	7
^{140}Ba	197	244	737	344	621	284	193	162	58
^{140}La	429	618	1406	670	1089	514	405	278	70
^{141}Ce	327	568	1116	525	940	525	517	544	107

*the grass samples used in the estimation of deposition velocities.

and ^{103}Ru. This is in agreement with the early observations on fractionation phenomena by Edvarson et al.[22], who predict that fresh fall-out is enriched in ^{95}Zr and depleted in ^{103}Ru, ^{140}Ba and ^{131}I, while ^{141}Ce is somewhere in between.

A few daily samples of precipitation and a monthly were also studied for fresh debris (table 3.3.3). A comparison between the rain and precipitation samples made a calculation of the washout-factors (W_o) possible (cf. table 3.3.5). The ratios were in general higher than the ratios observed for ^{90}Sr, which in the period 1960-72[1] showed a mean ratio of 0.99. The difference may be due to the higher dry deposition (which was included in the rain samples) of fresh debris than of old.

In grass with a dry matter yield of 44 $\pm$ 3 (1 SD) gm^{-2} (cf. table 3.3.6*), the ^{141}Ce levels were nearly constant (532 $\pm$ 24 pCi m^{-2}) from 15 October to 1 November. We may thus assume that the daily uptake by grass of ^{141}Ce from fall-out approximately equalled the daily field loss. During summer the retention half-life of radionuclides on grass is approx. 19 days and in winter 49 days (23). Let us assume that the half-life in autumn is in between these values, i.e. 34 days. The effective half-life of ^{141}Ce on grass then becomes 17 days and the daily field loss was thus 532 $(1 - e^{\frac{-\ln 2}{17}}) = 22$ pCi m^{-2} d^{-1}.

The mean air activity during the last half of October 1976 was $47 \cdot 10^{-3}$ pCi ^{141}Ce m^{-3}. Hence, the deposition velocity was $\frac{22}{47 \cdot 10^{-3}}$ $m \cdot d^{-1} = 0.5$ cm s^{-1}; if the retention half-life had been 19 days instead of 34 days, the deposition velocity would have changed to 0.7 cm s^{-1}. The winter half-life of 49 days gave 0.4 cm s^{-1}.

We may similarly estimate the deposition velocities of the other radionuclides: ^{95}Zr = 0.3 cm s^{-1}, ^{103}Ru = 0.1 cm s^{-1} and ^{140}Ba = 0.4 cm s^{-1}. In the case of iodine, we calculated the

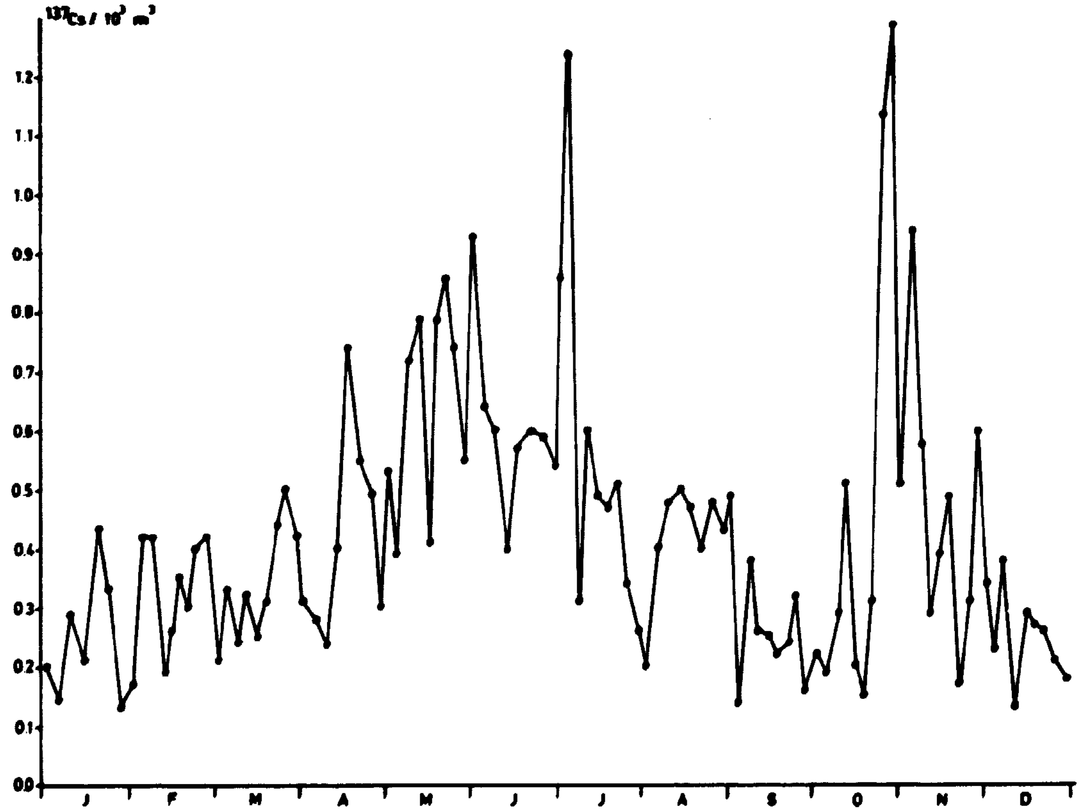

Fig. 3.3.1. Caesium-137 in ground level air at Risø in 1976.

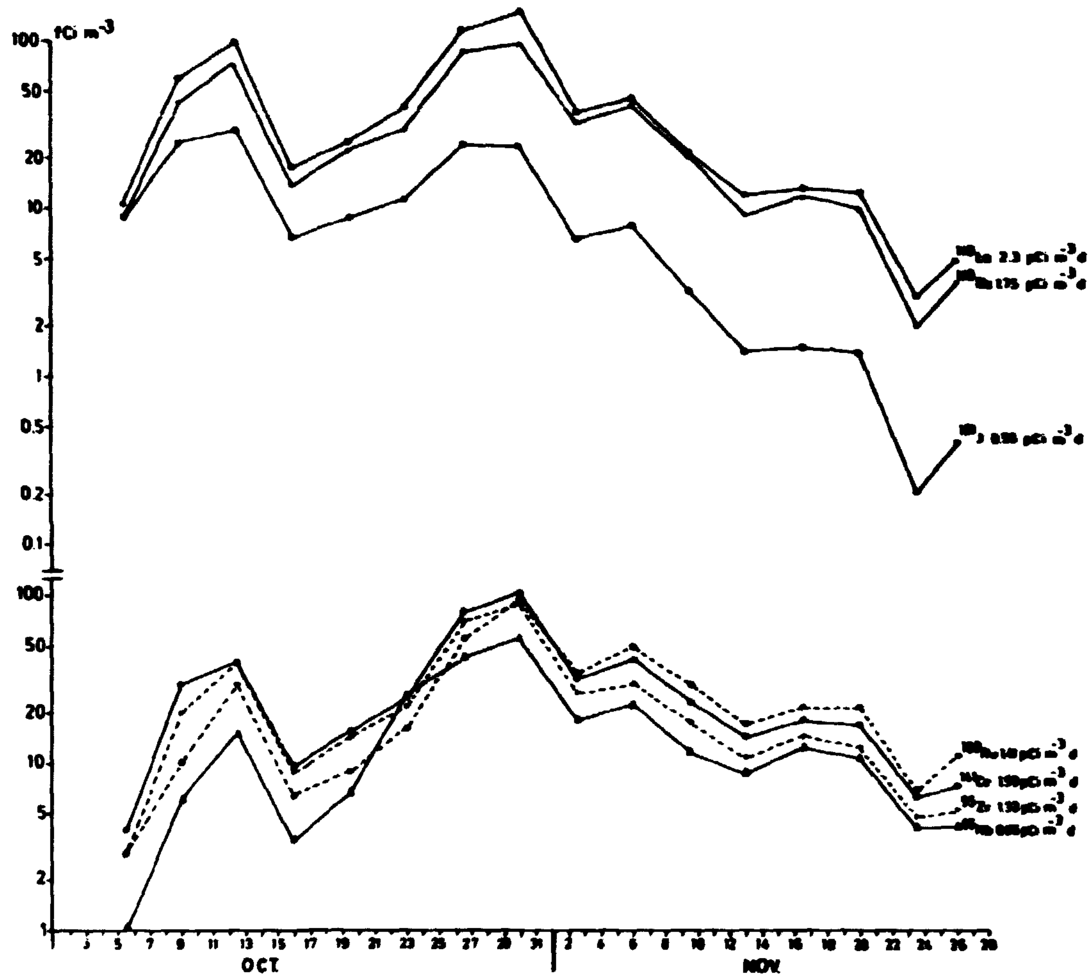

Fig. 3.3.2. Short lived fissions products in airborne debris from the Chineese test explosion 26 september 1976 collected in groundlevel air at Risø, October-November 1976. The time-integrated levels are indicated for the various radionuclides.

amount of ^{131}I deposited on the grass between two samplings from the levels measured in the grass, and under the assumption of effective half-lives varying from 5-8 days. The median value of the deposition velocities for ^{131}I calculated in this way was 1 cm s^{-1}, and the range of values was 0.1 - 3.1 cm s^{-1}. The values showed a decreasing tendency with time in agreement with expectations, as small particles (old fall-out) have a lower deposition velocity than large particles (fresh fall-out)[24]. It should, however, also be noticed that from 15-18 October the precipitation was substantial (31 mm), which may have increased deposition on the grass. The estimated deposition velocities on grass were of the same order of magnitude as given in the literature[25].

The transfer factors from air to grass were estimated for ^{131}I from the infinite, time-integrated ^{131}I levels in air and grass. We found 1 pCi $^{131}I\ m^{-3} \cdot d \sim 6.5$ nCi $^{131}I\ m^{-2}_{grass} \cdot d \sim 158$ nCi $^{131}I\ kg_{dry\ matter} \cdot d \sim 23$ nCi $^{131}I_{freshweight} \cdot d$.

3.4. γ-Spectroscopy of Bed Soil Samples from Roskilde Fjord

North of the outlet from the Waste Treatment Station (fig. 3.1.2.1), bed soil samples were collected with a HAPS sampler. Cores down to a depth of approx. 15 cm were analysed by Ge(γ) spectrometry. Table 3.4.1 shows the results, which are equal to those in previous years.

Table 3.4.1

Caesium-137 in fjord-bed soil collected in Roskilde Fjord in 1976 (HAPS) (145 cm^2)

Date	Depth in cm	pCi $^{137}Cs\ kg^{-1}$	mCi $^{137}Cs\ km^{-2}$
July 5 (I)	0-15	147	25
July 5 (II)	0-16	224	31
Sept. 30 (I)	0-15	187	31
Sept. 30 (II)	0-15	164	25
Mean		180	28
S.D.		33	3
S.E.		16	2

4. RADIOSTRONTIUM AND RADIOCAESIUM IN PRECIPITATION, SOIL AND GROUND-WATER IN DENMARK IN 1976

4.1. Strontium-90 in Precipitation

Samples of rain water were collected in 1976 from the State experimental farms (cf. fig. 4.1.1) in accordance with the principles laid down in Risø Report No. 63, p. 51[1].

Table 4.1.1 shows the results of the ^{90}Sr determinations and tables 4.1.2 and 4.1.3 the analysis of variance of the results. The variation with time was significant (P > 99%).

The maximum concentration in precipitation occurred in May-June, when the mean content in precipitation was 0.34 pCi ^{90}Sr/l (cf. also the air measurements in 3.2.1) while the maximum fall-out rate occurred in Nov.-Dec. 0.024 mCi $^{90}Sr/km^2$. Tables 4.1.2 and 4.1.3 show that the variation between locations was not signifi-

Table 4.1.1

Strontium-90 fall-out in Denmark in 1976

Period	Unit	Tylstrup	Studsgård	Ødum	Askov	St. Jyndevad	Blangstedgård	Tystofte	Virumgård	Abed	Åkirkeby	Ledreborg	Mean *
Jan-Feb	pCi l^{-1}	0.23	0.182	0.21	0.30	0.195	0.20	0.25	0.192	0.20 A	0.34	0.21	0.23
	mCi km^{-2}	0.0106	0.0168	0.0132	0.031	0.0156	0.0138	0.0105	0.0125	0.0140	0.0137	0.0094	0.0152
March-April	pCi l^{-1}	0.18	0.27	0.188	0.37	0.193 B	0.25	0.21	0.41	0.194	0.22	0.28	0.25
	mCi km^{-2}	0.0101	0.0126	0.0095	0.0145	0.0096	0.0081	0.0056	0.0096	0.0062	0.0095	0.0044	0.0095
May-June	pCi l^{-1}	0.36	0.38	0.21	0.32	0.43	0.25	0.57	0.28	0.30	0.30	0.196	0.34
	mCi km^{-2}	0.025	0.0171	0.0123	0.026	0.028	0.0188	0.039	0.022	0.018[illegible]	0.0187	0.0095	0.022
July-Aug	pCi l^{-1}	0.174	0.23	(0.23)	0.66	0.26	0.80	0.29	0.16	0.30	0.175	(0.21)	0.29
	mCi km^{-2}	0.0042	0.0027	0.0067	0.0179	0.025	0.0101	0.0080	0.0072	0.0140	0.0062	0.0084	0.0102
Sept-Oct	pCi l^{-1}	0.151	0.166	0.193	0.159	0.27	0.22	0.20	0.128	0.22	0.25	0.162	0.194
	mCi km^{-2}	0.030	0.024	0.0184	0.028	0.044	0.0165	0.0151	0.0079	0.020	0.0186	0.0116	0.022
Nov-Dec	pCi l^{-1}	0.26	0.136	0.193	0.27	(0.215)	0.23	0.164	(0.179)	0.38	0.22	0.119	0.22
	mCi km^{-2}	0.030	0.022	0.0149	0.035	0.029	0.027	0.0130	0.017	0.028	0.028	0.0071	0.024
1976	pCi l^{-1} $\bar{x}$	0.23	0.189	0.20	0.27	0.25	0.25	0.28	0.21	0.27	0.25	0.177	0.0230
	mCi km^{-2} Σ	0.110	0.095	0.075	0.152	0.147	0.094	0.091	0.076	0.101	0.091	0.050	0.103
mm precipitation Σ		409	503	378	556	579	381	320	369	376	368	203	432

*Ledreborg not included in mean. Figures in brackets calculated from VAR 3 [12].

Table 4.1.2

Analysis of variance of ln pCi ^{90}Sr l^{-1} precipitation in 1976 (from table 4.1.1)

Variation	SSD	f	s^2	v^2	P
Between locations	1.330	10	0.133	1.250	-
Between months	1.832	5	0.366	3.444	99%
Remainder	4.894	46	0.106		

Table 4.1.3

Analysis of variance of ln mCi ^{90}Sr km^{-2} precipitation in 1976 (from table 4.1.1)

Variation	SSD	f	s^2	v^2	P
Between locations	5.656	10	0.566	4.092	>99.95%
Between months	9.480	5	1.896	13.718	>99.95%
Remainder	6.358	46	0.138		

Table 4.1.4

The ratio ^{89}Sr/^{90}Sr in precipitation in Denmark in 1976

Location	November	December
Tylstrup	43	107 B
Studsgård	33	24 A
Ødum	15 B	20 B
Askov	4.2	40
St. Jyndevad	-	57
Blangstedgård	55	35
Tystofte	20 B	13 B
Virumgård	36	-
Abed	62	0.4 B
Åkirkeby	47	28 A
Ledreborg	32 B	25 A
$\bar{x}$ ± 1 S.E. (B exclusive)	40±7	35±5

cant. The mean levels for ten State experimental farms were 0.10 mCi ^{90}Sr/km^2 and 0.24 pCi ^{90}Sr/l. In Appendix A the country mean level (area-weighted) is estimated to be 0.10 mCi ^{90}Sr/km^2 for a mean precipitation of 523 mm (area-weighted), i.e. a quarter of the fall-out in 1975.

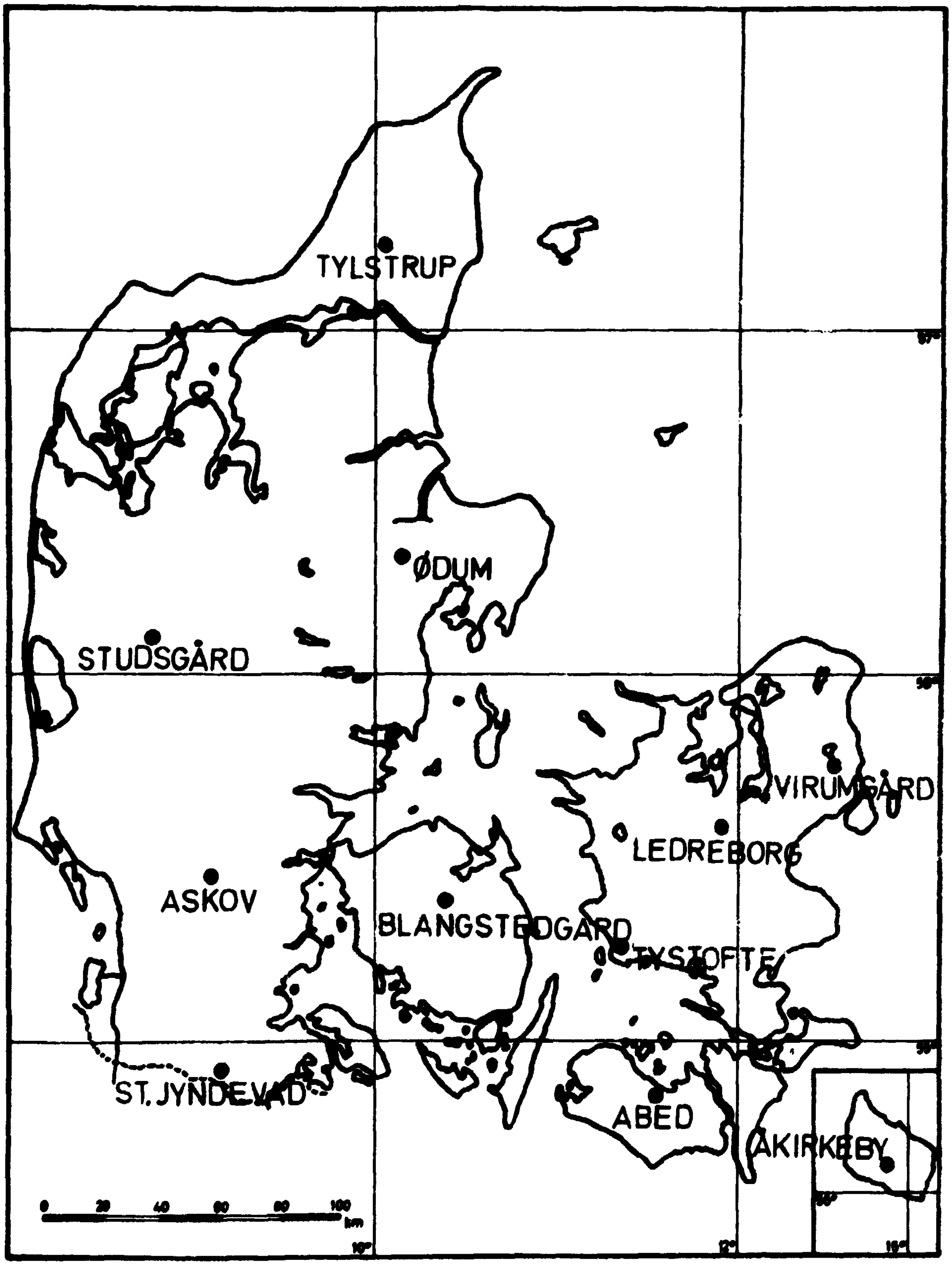

Fig. 4.1.1. State experimental farms in Denmark.

A comparison between the amounts of precipitation found in the rain gauges used by the Danish Meteorological Institute[9] and the amounts collected in our rain bottles at the same locations in 1976 showed a mean ratio of 1.22 $\pm$ 0.04 (1 SE) between the two sampling systems. The summer of 1976 was drier than normal. This resulted in a considerable evaporation from our rain bottles as compared to the rain gauges collected daily by the Danish Meteorological Institute; hence the ratio between the two systems became greater than usual.

Table 4.1.4 shows the presence of ^{89}Sr in precipitation collected in November and December. The ^{89}Sr/^{90}Sr ratios were equal to those observed in air (table 3.2.1.2).

4.2. Strontium-90, Caesium-137 and Plutonium in Soil

The aims of soil sampling in 1976 were partly to examine the importance of the application of manure to the fields (with respect to the levels of fall-out nuclides) and partly to repeat soil sampling at a few locations that showed unexpected activity levels in 1975. The results of these studies are given in tables 4.2.1-4.2.11.

The mean ratios between the accumulated activities in cultivated soils from Tylstrup, Askov, Blangstedgård, Abed and Risø with and without manure were for ^{90}Sr, 0.92 $\pm$ 0.09 (1 SE), and for ^{137}Cs, 1.17 $\pm$ 0.10 (mCi km^{-2}, 0-50 cm, cf. tables 4.2.1, 4.2.3 and 4.2.7 and in Risø Report No. 345[1] tables 4.2.6 and 4.2.8). We thus conclude that the application of manure apparently plays no major role for the levels of accumulated ^{90}Sr and ^{137}Cs in Danish soil. This is in accordance with the

Table 4.2.1

Strontium-90 in manured, cultivated soil in 1976 (mCi km^{-2})

Depth in cm	Tylstrup	Askov	Blangstedg.	Abed
0-20	29.1	28.6	32.8	26.4
20-30	13.4	9.3	10.5	10.1
30-50	8.2	4.9	3.0	2.1
Σ 0-30	42.5	37.9	43.3	36.5
Σ 0-50	50.7	42.8	46.3	38.6

Table 4.2.2

Strontium-90 in manured, cultivated soil in 1976 (pCi kg^{-1})

Depth in cm	Tylstrup	Askov	Blangstedg.	Abed
0-20	94	119	112	112
20-30	79	73	69	68
30-50	24	19	9.9	7.2
$\bar{x}$ 0-30*	88	103	97	95
$\bar{x}$ 0-50*	62	69	62	57
*weighted mean				

Table 4.2.3

Caesium-137 in manured, cultivated soil in 1976 (mCi km^{-2})

Depth in cm	Tylstrup	Askov	Blangstedg.	Abed
0-20	77	69	64	41
20-30	25	6.7	7.6	15.4
30-50	4.0	0.9 A	2.2	1.9
Σ 0-30	103	76	71	56
Σ 0-50	107	77	73	58

Table 4.2.4

Caesium-137 in manured, cultivated soil in 1976 (pCi kg^{-1})

Depth in cm	Tylstrup	Askov	Blangstedg.	Abed
0-20	248	288	216	174
20-30	150	52	50	103
30-50	11.6	3.5 A	7.3	6.5
$\bar{x}$ 0-30*	214	206	159	146
$\bar{x}$ 0-50*	129	123	98	86
*weighted mean				

Table 4.2.5

g K kg^{-1} in manured, cultivated soil in 1976

Depth in cm	Tylstrup	Askov	Blangstedg.	Abed
0-20	13.2	12.6	17.0	16.1
20-30	12.9	13.9	16.2	9.1
30-50	12.9	13.4	16.6	14.1
$\bar{x}$ 0-30*	13.1	13.0	16.7	13.4
$\bar{x}$ 0-50*	13.0	13.2	16.7	13.7

*weighted mean

Table 4.2.6

Strontium-90, Caesium-137 and Potassium-40 in uncultivated soil collected at Tystofte and Jyndevad in 1976

Depth in cm	Jyndevad					Tystofte				
	^{90}Sr mCi km^{-2}	^{90}Sr pCi kg^{-1}	^{137}Cs mCi km^{-2}	^{137}Cs pCi kg^{-1}	^{40}K g kg^{-1}	^{90}Sr mCi km^{-2}	^{90}Sr pCi kg^{-1}	^{137}Cs mCi km^{-2}	^{137}Cs pCi kg^{-1}	^{40}K g kg^{-1}
0-10	23.8	117	91	449	10.1	20.9	144	40.8	339	15.8
10-20	14.7	86	32.6	193	9.9	11.4	80	12.6	88	16.9
20-30	13.8	68	5.9	29	10.4	4.3	32	0.9	6.7	16.5
30-50	9.3	25	2.0 A	5.2 A	10.6	2.0	7.0	B.D.L	B.D.L	16.4
Σ 0-20	38.5		124			32.3		61		
Σ 0-30	52.3		130			36.6		62		
Σ 0-50	61.6		132			38.6		62		
$\bar{x}$ 0-20*		103		330	10.0		112		215	16.3
$\bar{x}$ 0-30*		91		224	10.1		87		148	16.4
$\bar{x}$ 0-50*		65		138	10.3		55		89	16.4

*weighted mean

Table 4.2.7

Strontium-90 and Caesium-137 in cultivated soil from Risø and Ledreborg, 1976 (mCi km^{-2})

Depth in cm	Risø				Ledreborg	
	cultivated		cultivated*		cultivated*	
	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs
0-20	23.8	44.2	30.1	60.0	36.2	72
20-30	9.5	11.9	7.4	4.0	16.7	16.5
30-50	4.3	3.8	1.9	1.9	4.3	1.7
Σ 0-30	33.4	56.2	37.5	64.0	52.9	89
Σ 0-50	37.7	60.0	39.4	65.9	57.2	90

*manured

Table 4.2.8

Strontium-90 and Caesium-137 in cultivated soil from Risø and Ledreborg, 1976 (pCi kg^{-1})

Depth in cm	Risø				Ledreborg	
	cultivated		cultivated*		cultivated*	
	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs
0-20	94	174	81	161	105	72
20-30	62	78	48	26	84	16.5
30-50	14.0	12.2	6.3	6.6	12.3	1.7
$\bar{x}$ 0-30**	82	138	71	122	98	89
$\bar{x}$ 0-50**	53	84	48	80	64	90

* manured

**weighted mean

Table 4.2.9

g K kg^{-1} cultivated soil from Risø and Ledreborg, 1976

Depth in cm	Risø		Ledreborg
	cultivated	cultivated*	cultivated*
0-20	19.3	17.2	17.1
20-30	18.6	17.1	18.3
30-50	18.2	16.3	19.1
$\bar{x}$ 0-30**	19.0	17.2	17.6
$\bar{x}$ 0-50**	18.7	16.9	18.2

* manured

**weighted mean

Table 4.2.10

The ratio $^{137}Cs/^{90}Sr$ in manured, cultivated soil in 1976 (from tables 4.2.1 and 4.2.3)

Depth in cm	Tylstrup	Askov	Blangstedgård	Abed	Mean	SD	SE
0-20	2.65	2.41	1.95	1.55	2.14	0.43	0.24
20-30	1.87	0.72	0.72	1.52	1.21	0.58	0.29
30-50	0.49	0.18	0.73	0.90	0.58	0.31	0.16
$\bar{x}$ 0-30	2.42	2.01	1.64	1.53	1.90	0.40	0.20
$\bar{x}$ 0-50	2.11	1.80	1.58	1.50	1.75	0.27	0.14

Table 4.2.11

The ratio $^{137}Cs/^{90}Sr$ in soil in 1976
(from tables 4.2.6 and 4.2.7)

Depth in cm	Jyndevad uncultivated	Tystofte uncultivated	Risø cultivated	Risø cultivated*	Ledreborg cultivated*
0-10	3.82	2.33			
0-20			1.86	1.99	1.99
10-20	2.22	1.11			
20-30	0.43	0.21	1.25	0.54	0.99
30-50	0.22	-	0.88	1.00	0.40
$\bar{x}$ 0-20	3.22	1.89			
$\bar{x}$ 0-30	2.49	1.69	1.68	1.71	1.68
$\bar{x}$ 0-50	2.14	1.61	1.59	1.67	1.57
*manured					

Table 4.2.12

Plutonium in uncultivated soil collected in Danish experimental farms in 1975
(mCi ^{239,240}Pu km^{-2})

	Tylstrup	Studs-gård	Askov	Blang-stedgård	Tystofte	Ledre-borg	Abed	Åkir-keby	Mean	SD	SE
0-10 cm	1.52	1.29	1.33	0.69	1.15	0.60	1.10	1.80	1.19	0.40	0.14
10-20 cm	0.16	0.25	0.52	0.55	0.46	0.34	0.16	0.24	0.34	0.16	0.06
20-30 cm	-	0.03	0.16	0.13	0.05	0.22	0.30	0.09	0.14	0.10	0.04
30-50 cm	Analyses of 50 g samples did not show Pu levels significantly different from zero activity										
0-50 cm	1.68	1.57	2.01	1.37	1.66	1.16	1.56	2.21	1.65	0.33	0.12

Table 4.2.13

Plutonium in cultivated soil collected in Danish experimental farms in 1975
(mCi ^{239,240}Pu km^{-2})

	Tylstrup	Studs-gård	Ødum	Askov	St. Jyn-devad	Blang-stedgård	Tystofte	Ledre-borg	Abed	Åkir-keby	Mean	SD	SE
0-20 cm	0.32	1.78	0.98	1.47	1.75	0.76	0.88	0.38	0.34	1.00	0.97	0.55	0.17
20-30 cm	0.07	0.09	0.11	0.10	-	0.22	0.60	0.11	0.09	0.17	0.17	0.17	0.06
30-50 cm	Analysis of 50 g samples did not show Pu levels significantly different from zero activity												
0-50 cm	0.39	1.87	1.09	1.57	1.75	0.98	1.48	0.49	0.43	1.17	1.12	0.55	0.17
Cultivated soils showed a lower ^{239,240}Pu content than uncultivated soils. The difference was probably significant ($p < 0.02$).													

estimates in 1975 (Risø Report No. 345[1] table 4.2.20), which indicated that the amounts of ^{90}Sr and ^{137}Cs removed by crops and later returned to the fields as manure were in the order of 5% of the deposit.

From table 4.2.6 and from Risø Report No. 345[1] it appears that the 1975 samples from Jyndevad were atypical. Especially the ^{90}Sr 1975 levels were anomalously high in the deeper layers. On the other hand, the ^{137}Cs seemed to have been underestimated in 1975. Table 4.2.7 shows that the 1976 samples of cultivated soils from Risø and Ledreborg contained more ^{90}Sr and ^{137}Cs than the 1975 samples, which were anomalously low (cf. in Risø Report No. 345[1] tables 4.2.6, 4.2.8, 4.2.13 and 4.2.15). We conclude that the few samples found in the 1975 material that deviated from the expected fall-out levels were atypical, because a repeated sampling at these locations in 1976 gave results in agreement with expectations based on earlier years' sampling at these locations. The extremely high levels found in the 1975 Ødum samples were not further investigated in the 1976 studies, but will be examined later in a special study.

The 1975 soil samples were used for a study of $^{239,240}Pu$ in Danish soils. The analysis was performed on 10 g of ashed soil by the classical Pu-analysis method described by TALVITE[19]. Most determinations were carried out as double or triple analyses. Plutonium concentrations below 30 cm were generally so low that the analyses were performed on 50 g aliquots. From tables 4.2.12 - 4.2.14 we conclude that the total accumulated $^{239,240}Pu$ in Danish uncultivated soil was 1.7 ± 0.1 (1 SE) mCi km^{-2} in 1975; $^{239,240}Pu/^{90}Sr$ = 0.032 ± 0.002 (1 SE) and $^{239,240}Pu/^{137}Cs$

Table 4.2.14

$^{239,240}Pu/^{137}Cs$ x 100 in uncultivated soil

collected at Danish experimental farms in 1975 (cf. Risø Report No. 345, table 4.2.3)

	Tylstrup	Studsgård	Ødum	Askov	St. Jyndevad	Blangstedgård	Tystofte	Ledreborg	Abed	Åkirkeby	Mean	SD	SE
0-10 cm	1.63	1.59	2.7	2.15	2.09	1.68	1.95	1.43	3.67	2.86	2.18	0.71	0.22
10-20 cm	2.00	3.01	2.3	1.68	1.88	1.31	2.80	1.36	0.44	1.04	1.78	0.79	0.25
20-30 cm	-	0.88	2.0	0.86	6.42	1.38	0.68	3.24	2.48	1.70	2.18	1.80	0.60
30-50 cm	-	-	2.2	-	-	-	-	-	-	-	-	-	-
0-50 cm	1.78	1.68	2.30	1.64	3.85	1.81	1.87	1.57	2.15	2.38	2.10	0.67	0.21

No significant variation could be found in the $^{239,240}Pu/^{137}Cs$ ratios with sampling depth, or between cultivated and uncultivated soils.

Table 4.2.15

$^{239,240}Pu/^{137}Cs$ x 100 in cultivated soil

collected at Danish experimental farms in 1975 (cf. Risø Report No. 345, table 4.2.8)

	Tylstrup	Studs-gård	Ødum	Askov	St. Jyn-devad	Blang-stedgård	Tystofte	Ledre-borg	Abed	Åkir-keby	Mean	SD	SE
0-20 cm	0.44	2.12	1.56	2.13	2.30	2.24	1.47	0.84	0.65	1.92	1.57	0.70	0.22
20-30 cm	0.27	0.76	0.80	0.89	-	1.79	3.82	6.11	0.75	1.42	1.85	1.91	0.64
0-50 cm	0.53	1.87	1.68	1.92	2.16	2.06	1.86	1.04	1.13	1.95	1.62	0.53	0.17

= 0.021 ± 0.002. These ratios are compatible with other findings assuming a $^{239,240}Pu/^{90}Sr$ ratio of 0.02 in air[21)], and thus of 0.028 in soil in 1975. Cultivated soil probably contained less $^{239,240}Pu$ than uncultivated soil, the mean ratio between the activity contents of the two soils being 0.6 ± 0.1 (1 SE). The $^{239,240}Pu$ activity showed the same vertical distribution as ^{137}Cs in the soil column, even in the case of an atypical ^{137}Cs distribution as found in Ødum (table 4.2.14).

4.3. Strontium-90 in Ground Water

As in previous years, ground water was collected in March from the nine locations selected by the Geological Survey of Denmark.

Table 4.3.1

Strontium-90 in ground water collected in March 1976

	^{90}Sr fCi l^{-1}	g Ca l^{-1}
Hvidsten	3	0.0708
Feldbak	18	0.0259
Rømø	15 A	0.0281
Rønne New*	19	0.0050
Rønne Old	2 A	0.0237
Hasselø	3	0.173
Fåretofte	B.D.L	0.0918
Kalundborg	7	0.0823
Ravnholt	B.D.L	0.0719
Fredericia	8	0.0708
Mean	194	0.0643
Median	5	0.0708

*collected in June.

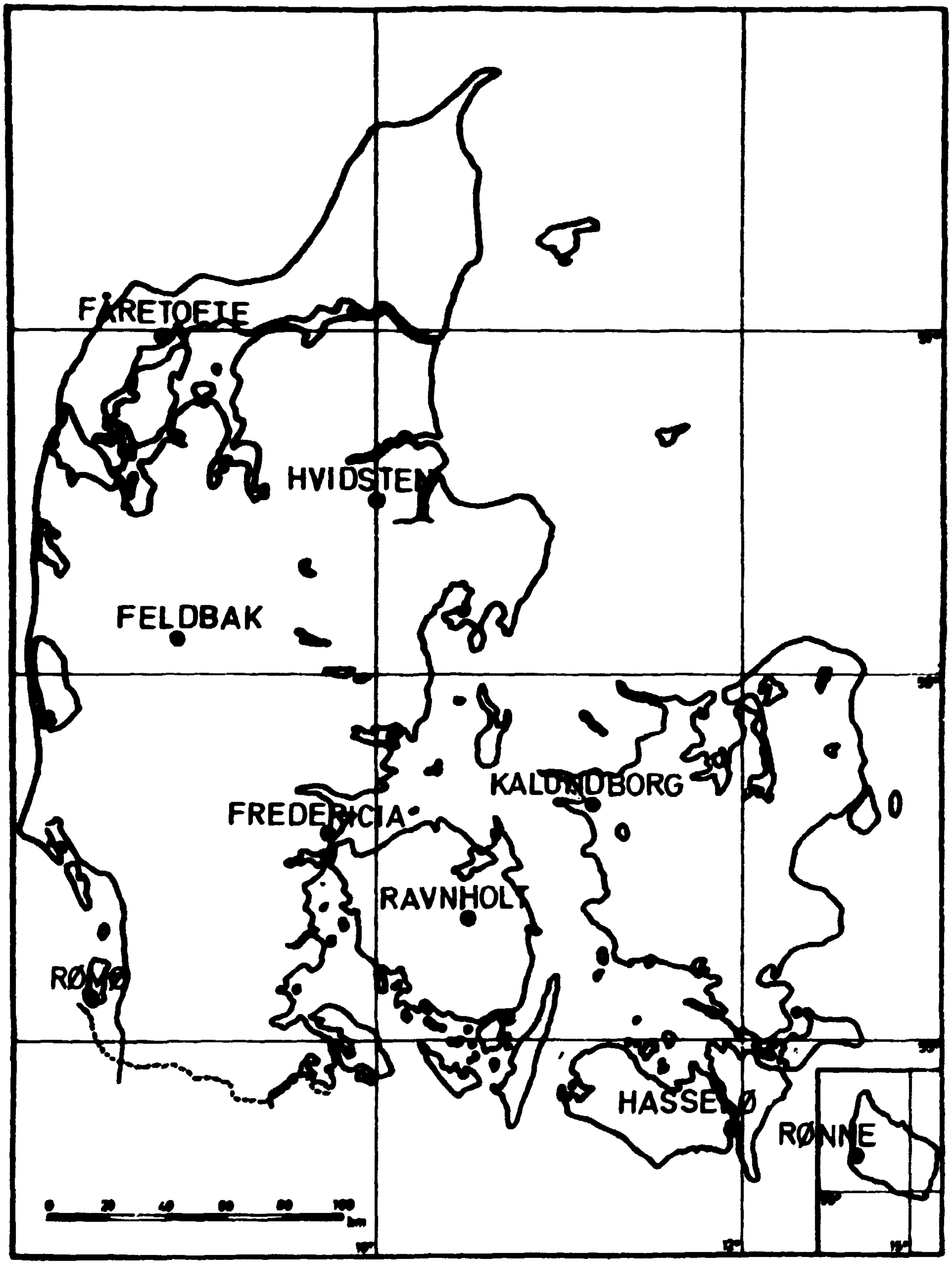

Fig. 4.3.1. Ground-water sampling locations in Denmark.

Figure 4.3.1 shows the sample locations and table 4.3.1 the results of the ^{90}Sr analyses (cf. also 5.8.4).

The median level of ^{90}Sr in 1976 was a third of that found in 1975 but nearly equal to the values observed in 1973 and 1974. Figure 4.3.2 shows the median levels in Danish ground water since 1961.

As appears from fig. 4.3.3, the ground water from Feldbak had showed no decreasing tendency by March 1976, but the March 1977 level were lower than both 1975 and 1976.

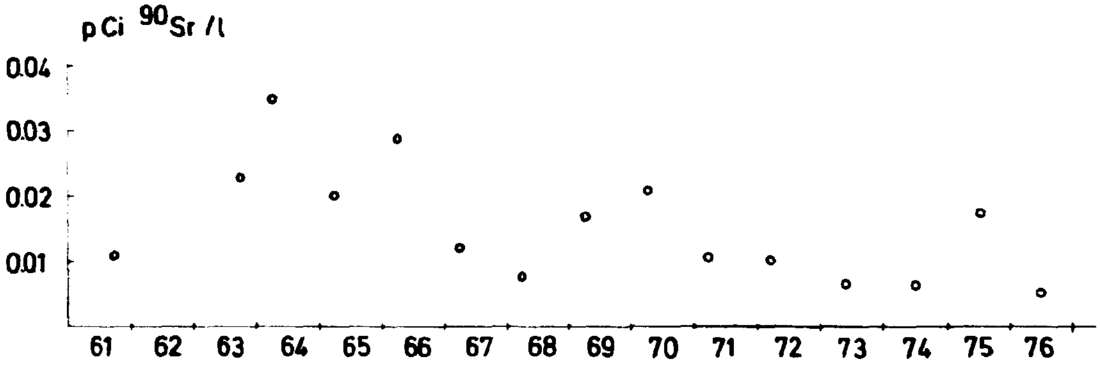

Fig. 4.3.2. Median ^{90}Sr levels in Danish ground water, 1961-76.

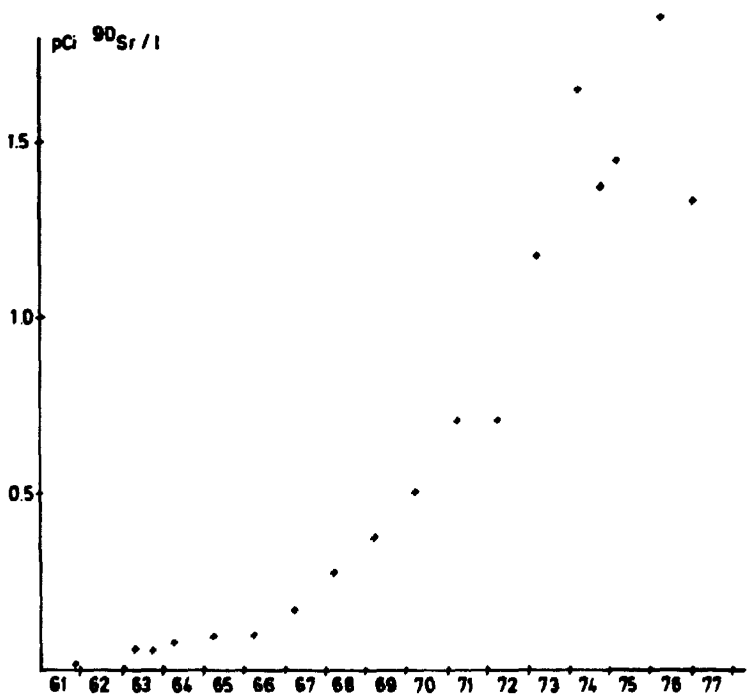

Fig. 4.3.3. Strontium-90 in ground water at Feldbak,1961-76.

5. RADIOSTRONTIUM AND RADIOCAESIUM IN DANISH FOOD IN 1976

5.1. Strontium-90 and Caesium-137 in Dried Milk from the Entire Country

As in previous years, monthly samples of dried milk were collected from seven locations in Denmark (cf. fig. 5.1.1) but the analyses for ^{90}Sr and ^{137}Cs were performed on pooled quarterly samples.

Table 5.1.1 shows the results of the ^{90}Sr determinations and table 5.1.2 the analysis of variance of the results. As in

Table 5.1.1

Strontium-90 (pCi (g Ca)$^{-1}$) in Danish dried milk in 1976

Month	Hjørring	Århus	Videbæk	Åbenrå	Odense	Ringsted	Lolland-Falster Møn	Mean
Jan Feb March	5.2	4.8	6.6	5.5	3.4	3.9	2.2	4.5
April May June	4.8	4.3	5.5	4.2	2.8	2.8	1.7	3.7
July Aug Sept	3.2	3.0	4.1	2.8	1.31 A	1.23 A	2.3 A	2.6
Oct	3.4	3.7	4.0	3.1	1.83	2.1	1.51	2.8
Nov	3.2	3.0	2.3	4.4	1.84	2.1	1.75	2.7
Dec	2.0	2.5	3.7	3.1	2.8	1.39	1.02 B	2.4
Mean	4.0	3.8	4.9	4.0	2.4	2.4	1.91	3.4

As 1 litre of milk contains 1.2 g Ca, the mean ^{90}Sr content in Danish milk produced in 1976 was 4.1 pCi l^{-1}.

recent years the time variation was significant for S.U.; the levels in the first quarter of the year were the highest. The S.U. mean level in 1976 was 3.4 pCi ^{90}Sr/g Ca, i.e. 0.8 times the 1975 mean.

As previously, milk from eastern Denmark showed significantly lower levels than that from Jutland.

Table 5.1.3 shows the results of the ^{137}Cs determinations and table 5.1.4 the analysis of variance of the results. The M.U. mean level in 1976 was 2.6 pCi ^{137}Cs/g K or 0.7 times the 1975 level.

Figures 5.1.2 - 5.1.5 show the S.U. and M.U. levels in dried milk compared with the predicted values (cf. Appendix C).

Table 5.1.2

Analysis of variance of ln pCi ^{90}Sr (g Ca)$^{-1}$ in dried milk in 1976 (from table 5.1.1)

Variation	SSD	f	s^2	v^2	P
Between locations	3.095	6	0.516	13.522	> 99.95%
Between quarters	1.753	3	0.584	15.316	> 99.95%
Remainder	0.687	18	0.038		

Table 5.1.3.

Caesium-137 (pCi (g K)$^{-1}$) in Danish dried milk in 1976

Month	Hjørring	Århus	Videbæk	Åbenrå	Odense	Ringsted	Lolland-Falster Møn	Mean
Jan Feb March	3.0	3.2	3.8	4.2	2.1	2.1	2.1	2.8
April May June	3.4	2.9	3.5	3.0	1.2	3.8	0.8 A	2.7
July Aug Sept	3.6	3.6	5.4	3.3	0.7 B	1.5 A	1.2 A	2.8
Oct Nov Dec	2.7	2.3	2.2	3.5	0.8 A	1.7	1.2±0.3	2.1
Mean	3.2	3.0	3.7	3.5	1.2	2.3	1.2	2.6

As 1 litre of milk contains approx. 1.66 g K, the mean ^{137}Cs content in Danish milk in 1976 was estimated at 4.3 pCi l^{-1}.

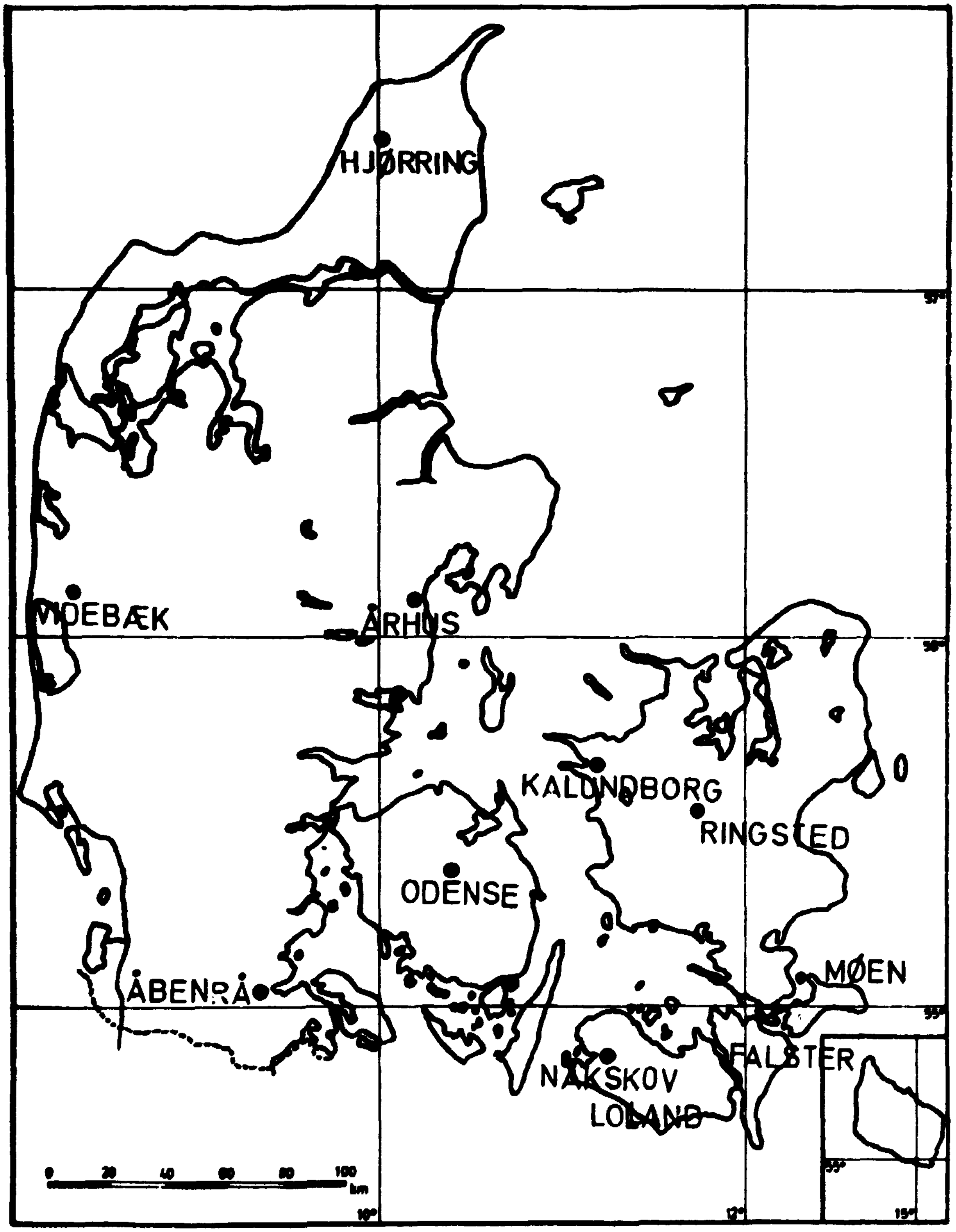

Fig. 5.1.1. Dried milk factories in Denmark.

Table 5.1.4

Analysis of variance of ln ^{137}Cs pCi (g K)$^{-1}$ in Danish dried milk 1976
(from table 5.1.3)

Variation	SSD	f	s^2	v^2	P
Between locations	6.581	6	1.097	12.476	>99.95%
Between quarters	0.403	3	0.134	1.527	-
Remainder	1.582	18	0.088		

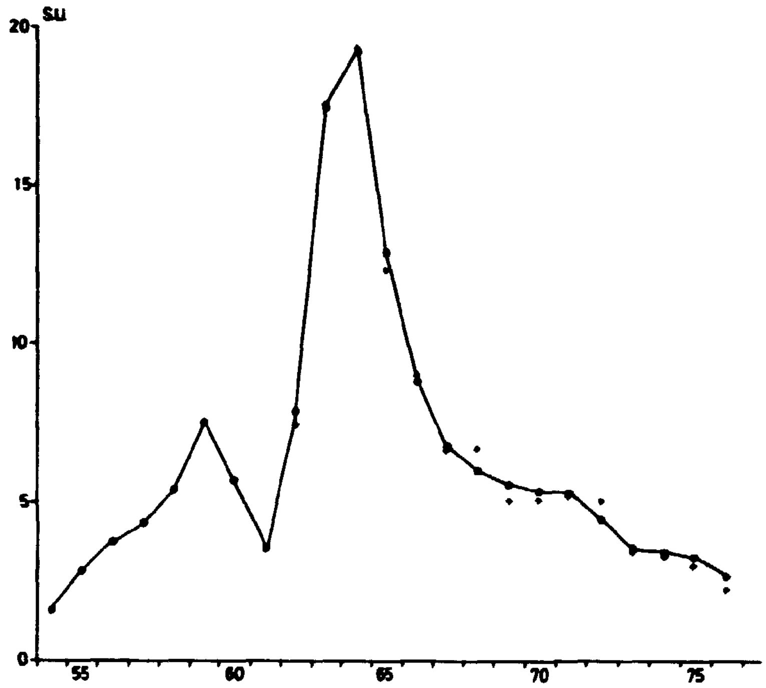

Fig. 5.1.2. A comparison between observed and calculated (curve, cf. appendix C) S.U.-levels in dried milk from the Islands.

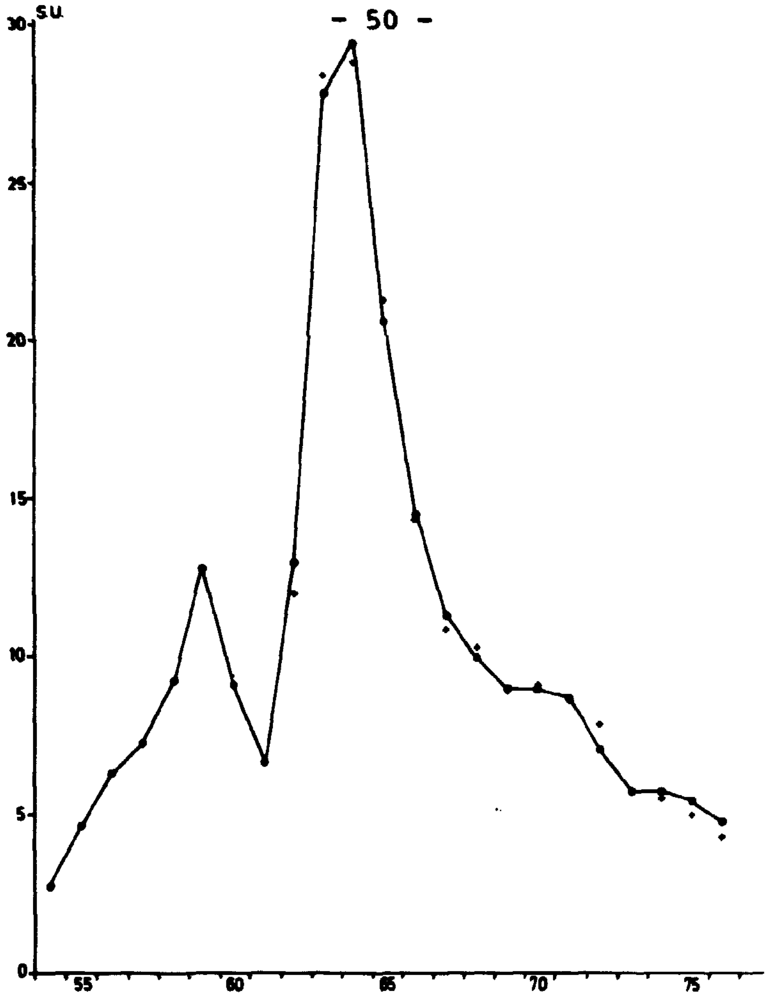

Fig. 5.1.3. A comparison between observed and calculated (curve, cf. appendix C) S.U.-levels in dried milk from Jutland.

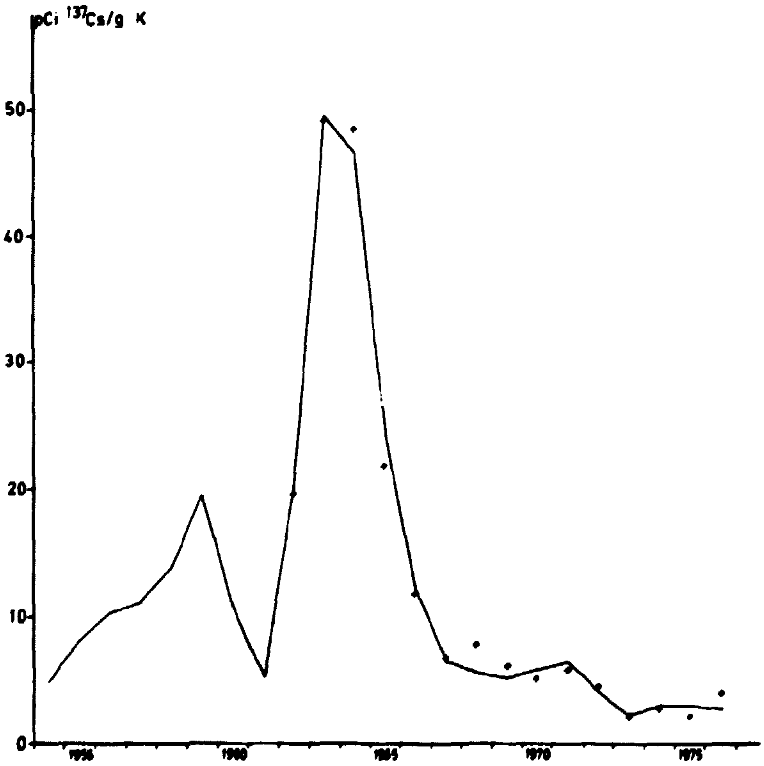

Fig. 5.1.4. A comparison between observed and calculated (curve, cf. appendix C) pCi ^{137}Cs/gK levels in dried milk from the Islands.

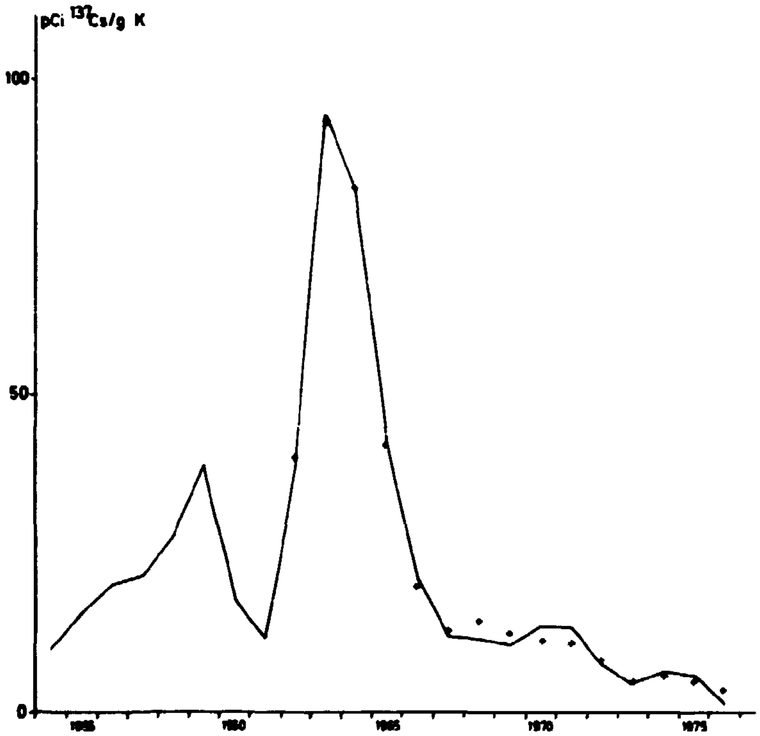

Fig. 5.1.5. A comparison between observed and calculated (curve, cf. appendix C) pCi ^{137}Cs/gK levels in dried milk from Jutland.

5.2. Strontium-90 and Caesium-137 in Fresh Milk from the Entire Country

The samples of fresh milk were collected in the eight zones and in Copenhagen (cf. fig. 5.2.1) in connection with the total-diet collection (cf. 5.7).

Table 5.2.1

Strontium-90 and Caesium-137 in fresh milk in 1976

Zone	June 1976			December 1976		
	pCi ^{90}Sr (g Ca)$^{-1}$	pCi ^{137}Cs (g K)$^{-1}$	pCi ^{137}Cs l^{-1}	pCi ^{90}Sr (g Ca)$^{-1}$	pCi ^{137}Cs (g K)$^{-1}$	pCi ^{137}Cs l^{-1}
I: North Jutland	4.4±0.3	3.6	6.2	3.3	1.93	3.1
II: East Jutland	4.2±0.2	2.3 A	3.7 A	2.9	1.45	2.3
III: West Jutland	4.4±0.0	3.0	4.9	3.7	2.21	3.7
IV: South Jutland	2.9±0.2	2.2 A	3.4 A	2.6 A	1.54	2.5
V: Funen	2.6±0.2	2.4 A	3.8 A	2.6	1.19 B	1.82 B
VI: Zealand	3.0±0.1	1.42 A	2.2 A	2.5	1.98 A	3.2 A
VII: Lolland-Falster	2.1	2.0 A	3.1 A	1.78	1.42 A	2.3 A
VIII: Bornholm	3.7±0.2	1.02 B	1.56 B	3.7	1.79	2.8
Mean	3.4	2.2	3.6	2.9	1.69	2.7
Copenhagen	3.4±0.1	1.72 B	2.[illegible] B	5.0	3.41	5.7
Population-weighted mean	3.6	2.2	3.6	3.5	2.2	3.6
Production-weighted mean	3.8	2.6	4.3	3.0	1.74	2.8
Relative error due to analysis	7%					

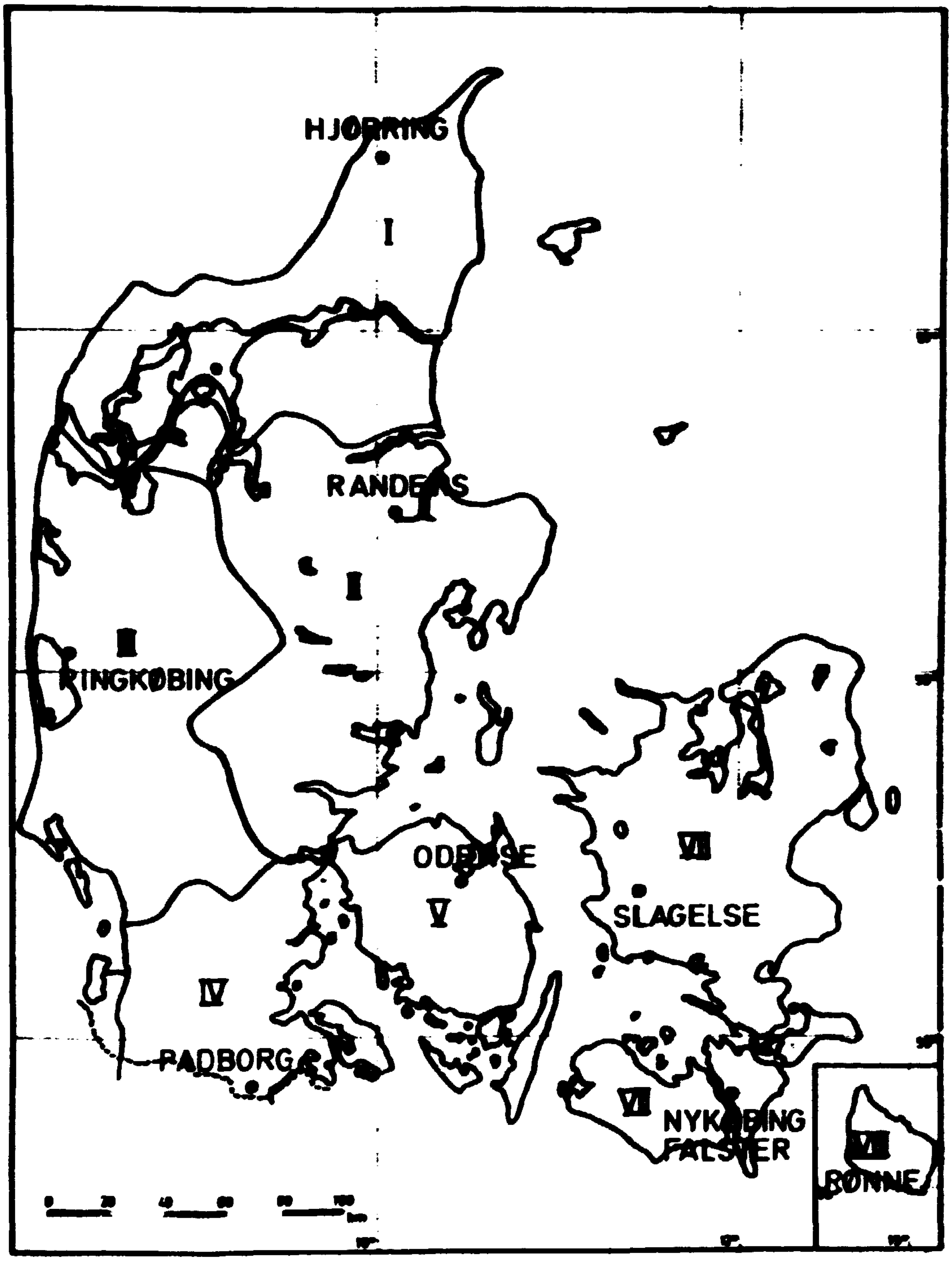

Fig. 5.2.1. Sample locations for fresh milk, bread and total diet.

Table 5.2.1 shows the results of the determinations of radiostrontium and ^{137}Cs in consumer milk.

The production-weighted means for ^{90}Sr and ^{137}Cs in Danish consumer milk in 1976 collected in June and December were 3.4 S.U. ($\sim$ 4.1 pCi $^{90}Sr/l$) and 2.2 M.U. or 3.6 pCi $^{137}Cs/l$, respectively.

As observed previously (except in 1973), fresh milk showed lower levels of caesium than the corresponding dried milk. Strontium showed slightly heigher levels in fresh milk than in the corresponding dried milk.

5.3. Strontium-90 and Caesium-137 in Grain from the Entire Country

As in previous years, grain samples were obtained from the State experimental farms (cf. fig. 4.1.1). Strontium-90 was determined as previously (Risø Report No. 63[1]), and ^{137}Cs was measured on pooled ashed samples by γ-spectrometry on a Ge-detector.

Table 5.3.1 shows the measurements of ^{90}Sr in grain in 1976. According to Appendix B, approx. 2/3 of all rye in Denmark is grown in Jutland and 1/3 in the eastern part of the country. As regards wheat, 4/5 is produced in eastern Denmark and 1/5 in Jutland. In the calculation of the means in tables 5.3.1 and 5.3.4. At Jutland is represented by five rye samples and seven wheat samples, while eastern Denmark contributes nine wheat and four rye samples. Thus the means in table 5.3.1 for wheat are higher than the production-weighted means for the country, while the rye means are perhaps too low. Table 5.3.2 gives the analysis of variance of the S.U. figures and table 5.3.3 that of the pCi $^{90}Sr/kg$ grain figures.

Tables 5.3.2 and 5.3.3 show that the variations in S.U. between species and locations were significant. Rye showed the highest S.U. levels and oats and barley the lowest, while the pCi $^{90}Sr/kg$ figures were higher in oats than in the other species.

As in previous years, the variation with location was highly significant; the mean pCi $^{90}Sr/kg$ level for grain from Jutland was 2.3 times that in eastern Denmark.

Table 5.3.4 shows the measurements of ^{137}Cs in grain in 1976. The ^{137}Cs levels in grain from 1976 were 0.55 times the

Table 5.3.1

Strontium-90 in Danish grain in 1976

	Rye		Barley		Wheat		Oats	
	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{90}Sr kg^{-1}	S.U.
Tylstrup	19.6	51	23	45	s:16.4	s:47	37	32
Studsgård	38	92	24	60	25	81		
Ødum	30	57	7.6	13.5	s: 9.6 w:14.7	s:20 w:42	20	18.3
Askov	w:21	w:49	21	39	29	62	38	43
St. Jyndevad	34	75	26	45	s:43 w:63	s: 74 w:121	45	51
Blangstedgård	23	68	8.9	16.6	8.8	30	13.8	13.4
Tystofte	10.8	27	9.4	17.1	s: 7.0 w:11.8	s:18.3 w:32	30	27
Ledreborg	w:15.5	39	8.9	19.6	s:14.4 w: 9.8	s:23 w:27	37	39
Abed			8.8	17.8	s: 4.8 w: 5.6	s:10.2 w:24	13.8	12.4
Åkirkeby	9.3	25	5.3	12.5	s: 8.6 w: 9.0	s:23 w:37	15.5	16.6
Mean	22	54	14.3	29	17.0	43	28	28

Table 5.3.2

Analysis of variance of ln S.U. in grain in 1976
(from table 5.3.1)

Variation	SSD	f	s^2	v^2	P
Between species	2.386	3	0.795	8.361	> 99.9%
Between locations	9.403	9	1.045	10.984	> 99.95%
Spec. x loc.	2.378	25	0.095	0.551	-
Remainder	1.036	6	0.173		

Table 5.3.3

Analysis of variance of ln pCi ^{90}Sr kg^{-1} grain in 1976
(from table 5.3.1)

Variation	SSD	f	s^2	v^2	P
Between species	3.571	3	1.190	10.575	> 99.95%
Between locations	11.280	9	1.253	11.133	> 99.95%
Spec. x loc.	2.814	25	0.113	1.714	-
Remainder	0.394	6	0.066		

Table 5.3.4

Caesium-137 in Danish grain in 1976

	Rye		Barley		Wheat		Oats	
	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{137}Cs kg^{-1}	M.U.
Jutland (zones I-IV)	16.0	2.71	6.8	1.26	7.0	1.78	13.0	1.85
The Islands (zones V-VIII)	6.5	1.16	0.86 B	0.22 B	3.0	0.63	6.5	1.28
Mean	11.8	2.02	3.8	0.74	4.8	1.13	9.4	1.53

The number of samples from the various species and areas of the country appears in table 5.3.1.

levels in 1975. The ratio between fall-out in May-August in 1976 and 1975 was 0.2.

We may thus conclude that the ^{137}Cs grain levels in 1976 were higher than expected from the fall-out in May-August (cf. Appendix C). This may be due to root-uptake of ^{137}Cs or to dry fall-out not captured by our rain collectors.

Comparing the S.U. levels in grain from the harvest of 1976 with the levels from 1975[1)], we find that the 1976 figures are 0.8 times the 1975 levels.

5.4. Strontium-90 and Caesium-137 in Bread from the Entire Country

In 1976, samples of white bread (75% extraction) and dark rye bread (100% extraction) were collected all over the country in June, and ^{90}Sr and ^{137}Cs were determined on pooled samples. The ^{137}Cs determinations were carried out on the ash by Ge γ-spectroscopy.

Tables 5.4.1 and 5.4.2 show the results. It is assumed that 1 kg flour yields approx. 1.35 kg bread[11)] and that wheat flour of 75% extraction contains 20% of the ^{90}Sr and 50% of the ^{137}Cs found in wheat grain[1)], while rye flour is 100% extraction. Hence we can compare the 1976 bread levels with the 1975 grain levels (cf. table 5.4.3).

Table 5.4.3 shows that the ^{90}Sr and ^{137}Cs levels in bread were in reasonable agreement with the above-mentioned model, expect for ^{90}Sr in rye bread, where the bread levels were lower than expected.

Table 5.4.1

Strontium-90 in Danish bread in June 1976

Zone	White bread		Rye bread	
	pCi kg^{-1}	S.U.	pCi kg^{-1}	S.U.
Jutland (Zones I-IV)	3.2	1.51	11.9	4.0
The Islands (Zones V-VIII)	1.90	0.92	10.9	3.6
Mean	2.6	1.22	11.4	3.8
Copenhagen	2.6	1.46	5.9	2.6
Population-weighted mean	2.7	1.33	10.0	3.5

Table 5.4.2

Caesium-137 in Danish bread in June 1976

Zone	White bread		Rye bread	
	pCi kg^{-1}	M.U.	pCi kg^{-1}	M.U.
Jutland (Zones I-IV)	4.5 A	2.7 A	13.5	4.3
The Islands (Zones V-VIII)	4.6	2.8	15.4	4.1
Mean	4.6	2.8	14.4	4.2
Copenhagen	4.3	1.7	6.9 B	2.5 B
Population-weighted mean	4.5	2.5	12.3	3.8

Table 5.4.3

A comparison between ^{90}Sr and ^{137}Cs levels in bread and grain in 1976

Nuclide	Species	Bread activity in June 1976 calculated as grain in pCi kg^{-1} (cf. text)	Activity in grain from harvest 1975[1)] pCi kg^{-1}	"Bread"/grain ratio
^{90}Sr	Wheat	18.2	20	0.9
	Rye	13.5	20	0.7
^{137}Cs	Wheat	12.2	9.3	1.3
	Rye	16.6	17.0	1.0

5.5. Strontium-90 and Caesium-137 in Potatoes from the Entire Country

The samples of potatoes were collected in September from ten of the State experimental farms (cf. fig. 4.1.1) and analysed for ^{90}Sr and ^{137}Cs (γ-spectroscopy of bulked samples of the ash).

Table 5.5.1 shows the ^{90}Sr and ^{137}Cs contents in potatoes. The mean contents for the country were 1.7 pCi ^{90}Sr/kg or 32 S.U. and 2.2 pCi ^{137}Cs/kg or 0.6 M.U. The levels were one half to one third of those of 1975.

Table 5.5.1

Strontium-90 and Caesium-137 in Danish potatoes in 1976

	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
Tylstrup	1.50±0.03	60 ±7	3.5	0.9
Studsgård	0.89 A	6.9 A		
Ødum	1.73	30		
Askov	4.5 ±0.5	71 ±9		
St. Jyndevad	1.41	49		
Blangstedgård	0.83±0.13 A	11.5±0.3	0.9 B	0.2 B
Tystofte	3.1	35		
Ledreborg	1.29±0.33	33 ±10		
Abed	0.94±0.22	15.5±3.1		
Rønne	0.71	10.9		
Mean	1.69	32	2.2	0.55

5.6. Strontium-90 and Caesium-137 in Vegetables and Fruit from the Entire Country

In 1976, as in previous years, vegetables and fruit were collected in the autumn from eight larger provincial towns, one in each of the eight zones. The samples were pooled into two groups one from Jutland and one from East Denmark (table 5.6.1).

Some of the γ-measurements were performed on bulked ash samples representing the entire country (cf. table 5.6.2).

The highest ^{90}Sr levels (pCi/kg) were found in kale, the lowest in apple.

Table 5.6.1

Strontium-90 in vegetables and fruit in 1976

	Cabbage		Carrot		Kale*		Celery root*		Beetroot*		Leek*		Apple	
	pCi kg^{-1}	S.U.	pCi kg^{-1}	S.U.	pCi kg^{-1}	S.U.	pCi kg^{-1}	S.U.	pCi kg^{-1}	S.U.	pCi kg^{-1}	S.U.	pCi kg^{-1}	S.U.
Jutland	6.7±0.6	11.5±1.1	2.6	8.6	38	26	16.3	38	19.5	70	9.7	41	1.10	22
The Islands	4.5±0.4	9.0±0.9	4.4	13.8	23	12.1	24	42	7.8	26	8.9	24	0.90	20
Mean	5.6	10.2	3.5	11.2	30	19.0	20	40	13.6	48	9.3	32	1.00	21

*Only one sampling location

Table 5.6.2

Caesium-137 in vegetables and fruit in 1976

	Cabbage		Carrot		Kale		Celery root		Beetroot		Leek		Apple	
	pCi kg^{-1}	M.U.	pCi kg^{-1}	M.U.	pCi kg^{-1}	M.U.	pCi kg^{-1}	M.U.	pCi kg^{-1}	M.U.	pCi kg^{-1}	M.U.	pCi kg^{-1}	M.U.
Jutland					11.3	3.4	0	0	6.1	1.12	2.9 A	1.21A		
The Islands					0	0	0	0	3.2 A	0.81 A	7.0 A	1.14A		
Denmark (Mean)	2.11	1.04	0.4 B	0.1 B	5.6	1.7	0	0	4.6	0.97	5.0	1.18	1.89	1.52

Table 5.6.3

Calculated ^{90}Sr and ^{137}Cs mean levels in vegetables in 1976

Daily intake in g	Species	^{90}Sr pCi kg^{-1}	S.U.	^{137}Cs pCi kg^{-1}	M.U.
50	Leaf vegetables (cabbage, kale)	6.6	10.6	2.2	1.07
30	Root vegetables (carrot, celery, beet, leek)	9.5	28	2.6	0.61
40	Pea	(4.5)	(17.6)	(3.7)	(0.7)
120	Vegetable total	6.6	17.3	2.8	0.83

The ^{90}Sr levels in peas are those found in 1973

The ^{137}Cs levels in peas are those found in 1974

Table 5.6.3 shows a calculation of the mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1976 (^{90}Sr in peas was taken to be the same as the 1973 figures). The levels are the population-weighted means.

The 1976 levels in Danish fruit were calculated from apples and the mean levels in Danish fruit were thus 1.0 pCi ^{90}Sr/kg and 1.9 pCi ^{137}Cs/kg.

5.7. Strontium-90 and Caesium-137 in Total Diet from the Entire Country

In 1976 total-food samples representing an average Danish diet according to E. Hoff-Jørgensen (cf. Appendix B in Risø

Report No. 63[1]) were collected from eight towns each representing one of the eight zones (cf. fig. 5.2.1) and from Copenhagen. The sampling took place as previously in June and December.

Tables 5.7.1 and 5.7.2 show the results. In contrast to previous experience, it was not possible in 1976 to see any significant difference in the diet levels from Jutland and the Islands.

Figures 5.7.1 - 5.7.4 show the zone mean levels (not population-weighted) of S.U. and M.U. in total diet compared with the predicted values (cf. Appendix C).

Table 5.7.1

Strontium-90 and Caesium-137 in Danish total diet collected in June 1976

Zone	pCi ^{90}Sr (g Ca)$^{-1}$	pCi ^{90}Sr day^{-1}	g Ca day^{-1}	pCi ^{137}Cs (g K)$^{-1}$	pCi ^{137}Cs day^{-1}
I: North Jutland	3.4±0.0	5.3±0.0	1.54±0.00	2.3	8.8
II. East Jutland	2.9±0.2	5.3±0.4	1.79±0.00	2.0	8.1
III: West Jutland	4.2±0.2	6.5±0.2	1.56±0.0[illegible]	1.7 A	6.2 A
IV: South Jutland	3.0±0.2	5.1±0.3	1.70±0.01	2.2	8.1
V: Funen	3.2±0.0	5.6±0.1	1.74±0.00	2.8	10.1
VI: Zealand	3.5±0.0	5.7±0.1	1.63±0.01	1.9	7.8
VII: Lolland-Falster	2.9±0.2	4.8±0.3	1.66±0.00	2.7	9.7
VIII: Bornholm	4.8±0.3	7.9±0.4	1.66±0.00	2.4	10.4
Mean	3.5	5.8	1.66	2.2	8.6
Copenhagen	3.3±0.1	5.0±0.2	1.50±0.01	2.6	10.8
Population-weighted mean	3.4	5.5	1.62	2.2	8.9
Relative error due to analysis	7%	6%	1%		

Table 5.7.2

Strontium-90 and Caesium-137 in Danish total diet collected in December 1976

Zone	pCi ^{90}Sr (g Ca)$^{-1}$	pCi ^{90}Sr day^{-1}	g Ca day^{-1}	pCi ^{137}Cs (g K)$^{-1}$	pCi ^{137}Cs day^{-1}
I: North Jutland	3.9±0.0	6.2±0.0	1.58±0.02	3.2	12.0
II. East Jutland	3.7±0.4	5.8±0.6	1.55±0.00	3.3	12.4
III: West Jutland	3.8±0.1	5.8±0.3	1.53±0.02	3.8	14.2
IV: South Jutland	3.[illegible]±0.1	5.0±0.2	1.44±0.00	1.6	6.2
V: Funen	2.7±0.1	4.7±0.2	1.74±0.01	2.3	8.7
VI: Zealand	2.7±0.2	4.4±0.4	1.66±0.00	1.6 A	5.8 A
VII: Lolland-Falster	3.1±0.3	5.8±0.6	1.88±0.02	3.[illegible]	14.1
VIII: Bornholm	3.9±0.2	6.2±0.4	1.60±0.02	1.9	8.2
Mean	3.4	5.5	1.62	2.7	10.2
Copenhagen	3.3±0.2	5.1±0.3	1.55±0.01	3.3	12.4
Population-weighted mean	3.4	5.3	1.59	2.9	11.0
Relative error due to analysis	9%	10%	1%		

The 1976 levels in total diet were approx. 2/3 of the 1975 levels.

From the total-diet sampling it is possible to estimate the mean levels of ^{90}Sr and ^{137}Cs in the Danish diet in 1976. For the period January-April 1976, the ^{90}Sr level in the total diet is assumed to have been equal to that measured in December 1975, Risø Report No. 345[1]. For the period May-September we assume the level to have corresponded to that measured in June 1976. The December 1976 figures are taken to represent the last three months of the year. The population-weighted mean of ^{90}Sr in total-diet samples was 5.2 pCi ^{90}Sr/g Ca in December 1975. Hence the mean content in the total diet in 1976 was 4.0 pCi ^{90}Sr/g Ca or 7 pCi ^{90}Sr/day.

Similarly, the ^{137}Cs content in the Danish diet in 1976 was estimated to be 10 pCi ^{137}Cs/day or 2.6 pCi ^{137}Cs/g K.

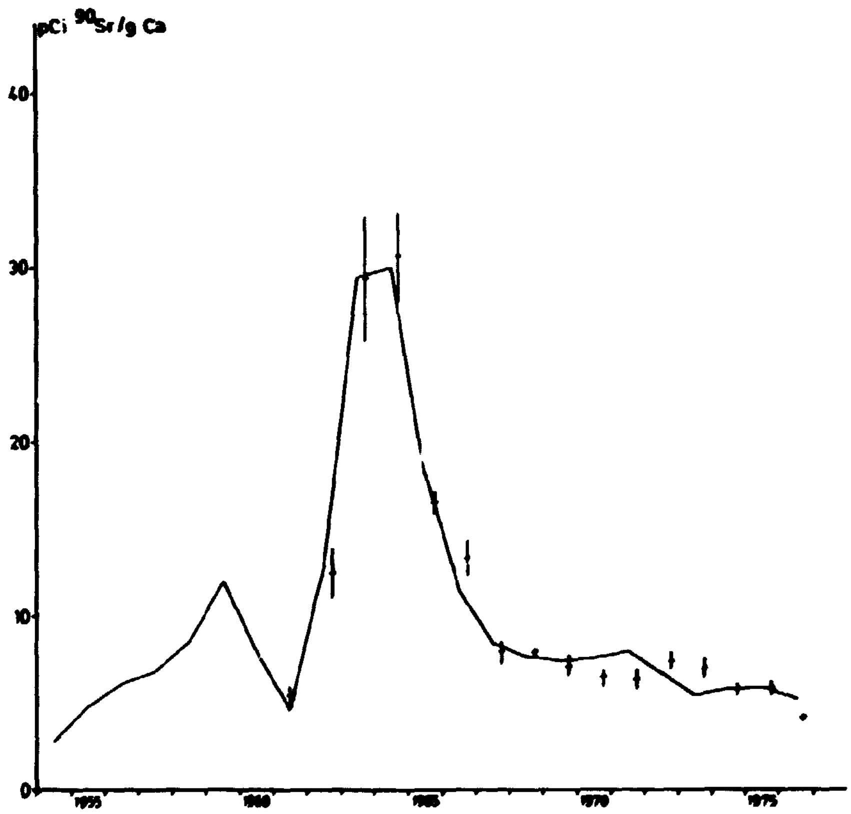

Fig. 5.7.1. A comparison between observed (± 1 S.E.) and calculated (curve, cf. appendix C) S.U.-levels in total diet from the Islands.

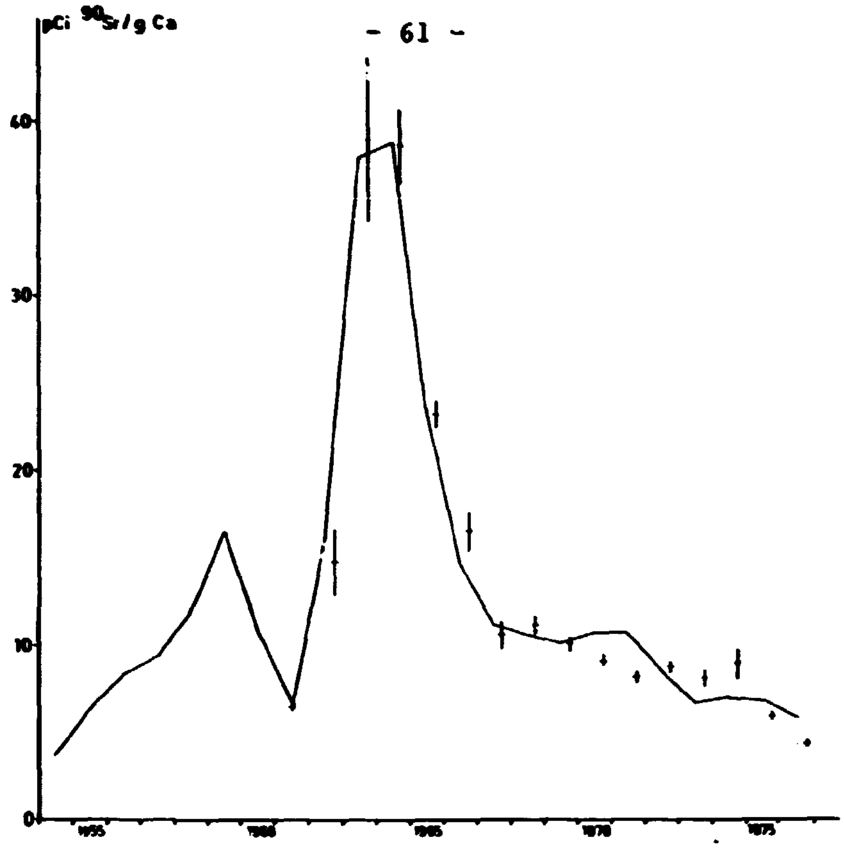

Fig. 5.7.2. A comparison between observed (± 1 S.E.) and calculated (curve, cf. appendix C) S.U.-levels in total diet from Jutland.

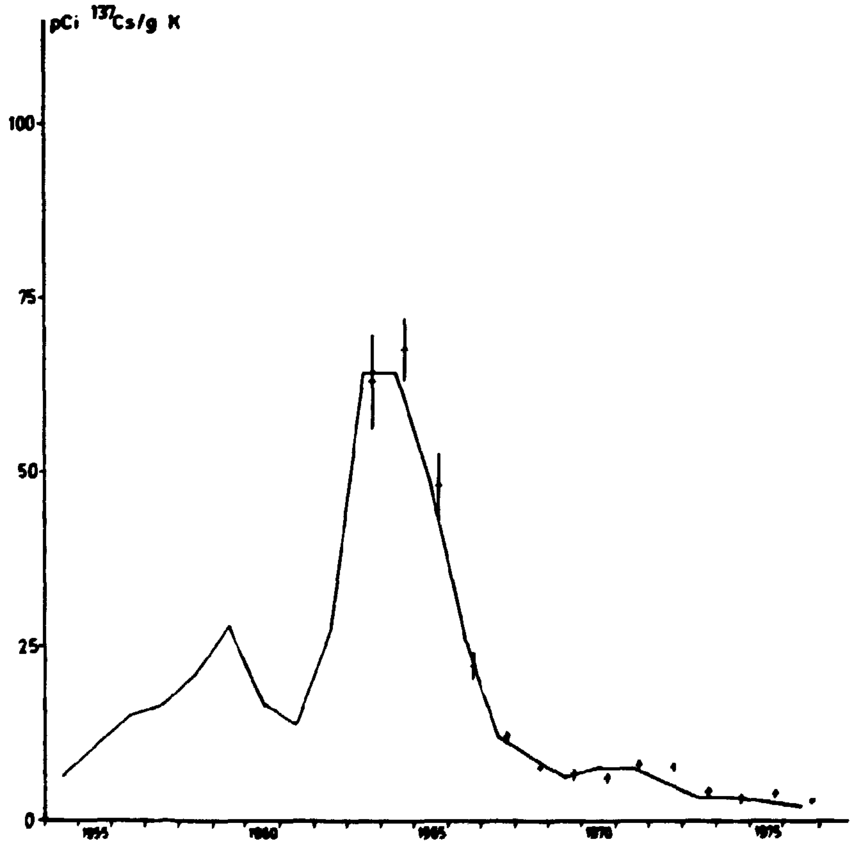

Fig. 5.7.3. A comparison between observed (± 1 S.E.) and calculated (curve, cf. appendix C) pCi ^{137}Cs/gK levels in total diet from the Islands.

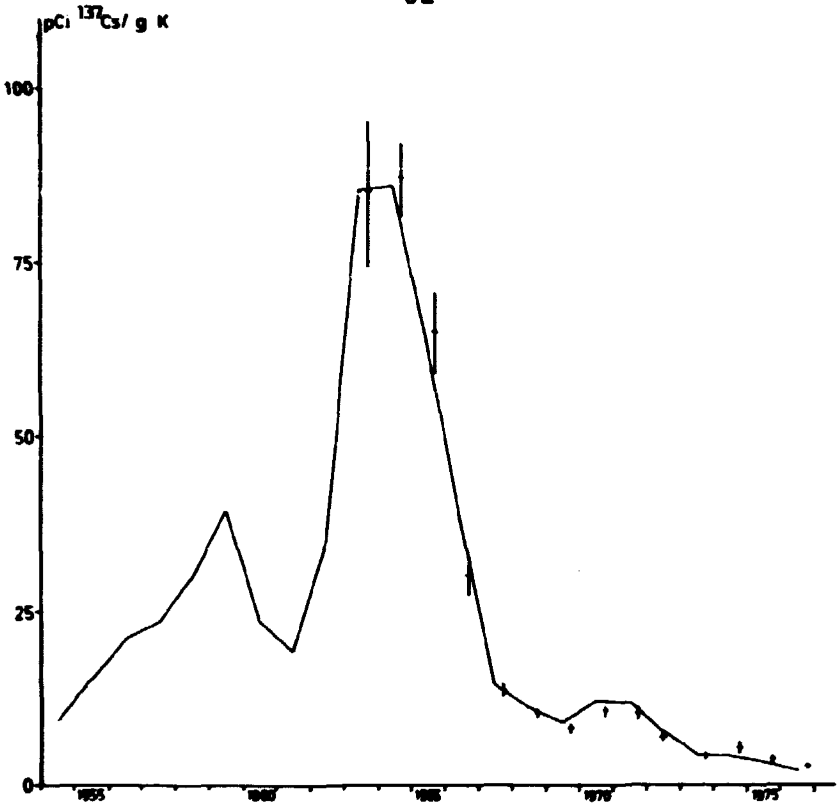

Fig. 5.7.4. A comparison between observed (± 1 S.E.) and calculated (curve, cf. appendix C) pCi ^{137}Cs/gK levels in total diet from Jutland.

5.8. Strontium-90 and Caesium-137 in Miscellaneous Foodstuffs

5.8.1. Strontium-90 and Caesium-137 in Meat

Pork and beef samples were collected in Copenhagen in three large shops in June and November. Table 5.8.1 shows the results.

Table 5.8.1

Strontium-90 and Caesium-137 in pork and beef from Copenhagen in 1976

Species	Unit	June	November	Mean
Pork	pCi ^{90}Sr kg^{-1}	0.39 B	0.26 B	0.32
	pCi ^{90}Sr $(g\ Ca)^{-1}$	5.9 B	1.27 B	3.6
	pCi ^{137}Cs kg^{-1}	27	17.6	22
	pCi ^{137}Cs $(g\ K)^{-1}$	8.4	5.3	6.8
Beef	pCi ^{90}Sr kg^{-1}	0.98 A	0.38 B	0.68
	pCi ^{90}Sr $(g\ Ca)^{-1}$	17.4 A	3.7 B	10.6
	pCi ^{137}Cs kg^{-1}	14.9	49	32
	pCi ^{137}Cs $(g\ K)^{-1}$	4.5	17.8	11.2

5.8.2. Strontium-90 and Caesium-137 in Fish

Fish samples were collected in inner Danish waters together with the sea-water samples (cf. 7). Table 5.8.2 shows the results. The mean levels in fish from 1976 were 59 pCi ^{137}Cs/kg (8 samples) and 0.52 pCi ^{90}Sr/kg (8 samples).

Table 5.8.2

Strontium-90 and Caesium-137 in fish collected in 1976

Species	Location		^{90}Sr pCi kg^{-1}	^{90}Sr pCi (g Ca)$^{-1}$	^{137}Cs pCi kg^{-1}	^{137}Cs pCi (g K)$^{-1}$
Plaice	The north part of the Great Belt	Meat	0.1 B	0.1 B	34	10.0
		Bone	-	0.64	-	-
Herring	The north part of the Great Belt	Meat	0.3 B	0.8 B	54	14.1
		Bone	-	0.08 B	-	-
Cod	The north part of the Great Belt	Meat	0.2 B	0.1 B	50	13.4
		Bone	-	0.35	-	-
Plaice	Rødbyhavn	Meat	1.00 A	1.04 A	82	23
		Bone	-	0.80	-	-
Herring	Rødbyhavn "Fehmern Belt"	Meat	0.3 B	0.4 B	64	15.0
		Bone	-	0.09 B	-	-
Cod	Rødbyhavn "Fehmern Belt"	Meat	1.79	1.03	67	18.8
		Bone	-	1.12	-	-
Herring	Roskilde fjord	Meat	0.2 B	0.2 B	76	18.3
		Bone	-	0.1 B	-	-
Eel	Roskilde fjord	Meat	0.28 A	0.69 A	41	15.1
		Bone	-	0.59	-	-

5.8.3. Strontium-90 and Caesium-137 in Various Foods

As compared with the corresponding sampling in 1974[1)], the levels were generally lower in 1976.

Table 5.8.3

Strontium-90 and Caesium-137 in various foods collected in December 1976

	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
Orange	10.7	12.5	2.8	2.1
Banana	0.43 A	15.1 A	1.4 B	0.4 B
Coffee	6.8 A	5.6 A	38	1.8
Tea	8.2	19.4	31	2.1

5.9. Estimate of the Mean Contents of ^{90}Sr and ^{137}Cs in the Human Diet in Denmark in 1976

5.9.1. The Annual Quantities

The annual quantities are calculated by multiplication of the daily quantities by 365 (as stated by E. Hoff-Jørgensen, cf. Risø Report No. 63, table B[1]).

Table 5.9.1

Estimate of the ^{90}Sr content in grain products consumed per capita in 1976

Type	Fraction from harvest 1975			Fraction from harvest 1976			Total
	kg flour	pCi kg^{-1}	pCi	kg flour	pCi kg^{-1}	pCi	pCi
Rye flour (100% extraction)	21.9	20	438	7.3	22	161	599
Wheat flour (75% extraction)	32.9	4.0	132	10.9	3.4	37	169
Grits	5.5	12.4	68	1.8	11.2	20	88
Total	60.3	10.6	639	20.0	10.9	218	857

5.9.2. Milk and Cream

The ^{90}Sr and ^{137}Cs contents per kg milk were calculated from the annual mean values for dried milk (cf. tables 5.1.1 and 5.1.3). 1 kg ∿ 1 l milk, containing approx. 1.2 g Ca and 1.66 g K. Hence the mean contents in milk were 4.1 pCi $^{90}Sr/kg$ and 4.3 pCi $^{137}Cs/kg$.

Table 5.9.2

Estimate of the ^{137}Cs content in grain products consumed per capita in 1976

Type	Fraction from harvest 1975			Fraction from harvest 1976			Total
	kg flour	pCi kg^{-1}	pCi	kg flour	pCi kg^{-1}	pCi	pCi
Rye flour (100% extraction)	21.9	17	372	7.3	11.8	86	458
Wheat flour (75% extraction)	32.9	4.6	151	10.9	2.4	26	177
Grits	5.5	12.3	68	1.8	7.0	12.6	81
Total	60.3	9.8	591	20.0	6.2	125	716

5.9.3. Cheese

One kg of cheese contains approx. 8.5 g Ca and 1.2 g K. The ^{90}Sr and ^{137}Cs contents in cheese were calculated from these figures and from the S.U. and M.U. levels in dried milk (cf. tables 5.1.1 and 5.1.3). One kg of cheese appeared to contain 28.9 pCi ^{90}Sr and 3.1 pCi ^{137}Cs.

Table 5.9.3

Estimate of the mean content of ^{90}Sr in the human diet in Denmark in 1976

Type of food	Annual quantity in kg	pCi ^{90}Sr per kg	Total pCi ^{90}Sr	Percentage of total pCi ^{90}Sr in food
Milk and cream	164.0	4.1	672	27.9
Cheese	9.1	28.9	263	10.9
Grain products	80.3	10.7	859	35.6
Potatoes	73.0	1.7	124	5.2
Vegetables	43.8	6.6	289	12.0
Fruit	51.1	2.3	118	4.9
Meat	54.7	0.4	21.9	0.9
Eggs	10.9	0.9	9.8	0.4
Fish	10.9	0.5	5.4	0.2
Coffee and tea	5.5	7.3	40	1.7
Drinking water	548	0.02	11	0.3
Total			2413	

The mean calcium intake was estimated at 620 g (approx. 200-250 g Creta praeparata). Hence the $^{90}Sr/Ca$ ratio in the total diet was 3.9 S.U. in 1976.

5.9.4. Grain Products

Tables 5.9.1 and 5.9.2 show the estimates of ^{90}Sr and ^{137}Cs, respectively, in grain products consumed in 1976. From these tables, the activity levels in grain products were estimated at 10.7 pCi ^{90}Sr/kg and 8.9 pCi ^{137}Cs/kg.

Table 5.9.4

Estimate of the mean content of ^{137}Cs in the human diet in Denmark in 1976

Type of food	Annual quantity in kg	pCi ^{137}Cs per kg	Total pCi ^{137}Cs	Percentage of total pCi ^{137}Cs in food
Milk and cream	164.0	4.3	705	17.3
Cheese	9.1	3.1	12	0.3
Grain products	80.3	8.9	716	17.6
Potatoes	73.0	2.2	161	4.0
Vegetables	43.8	2.8	123	3.0
Fruit	51.1	2.0	102	2.5
Meat	54.7	25.3	1384	34.0
Eggs	10.9	2.7	29	0.7
Fish	10.9	59	643	15.8
Coffee and tea	5.5	35.7	196	4.8
Drinking water	548	0	0	0
Total			4071	

As the approximate intake of potassium was 1365 g, the pCi ^{137}Cs $(g\ K)^{-1}$ ratio was approx. 3.0. The daily mean intake in 1976 was 11.2 pCi ^{137}Cs per capita.

5.9.5. Potatoes

The figures in table 5.5.1 were used, i.e. 1.7 pCi ^{90}Sr/kg and 2.2 pCi ^{137}Cs/kg.

5.9.6. Vegetables

Table 5.6.3 shows the calculation of ^{90}Sr and ^{137}Cs in Danish vegetables consumed in 1976. The mean contents were 6.6 pCi ^{90}Sr/kg and 2.8 pCi ^{137}Cs/kg.

5.9.7. Fruit

The levels in imported fruit in 1976 are assumed to be equal to the mean levels found in oranges and bananas collected in Copenhagen in 1976, i.e. 5.6 pCi ^{90}Sr/kg and 2.1 pCi ^{137}Cs/kg. The mean levels in Danish fruit (apples) in 1976 were 1.0 pCi ^{90}Sr/kg and 1.9 pCi ^{137}Cs/kg (cf. 5.6). The daily mean consumption of fruit consisted of 100 g of Danish and 40 g of foreign origin. Hence the mean contents in fruit were 2.3 pCi ^{90}Sr/kg and 2.0 pCi ^{137}Cs/kg.

5.9.8. Meat

The annual mean values of ^{90}Sr and ^{137}Cs in meat were calculated from table 5.8.1: 0.4 pCi ^{90}Sr/kg and 25.3 pCi ^{137}Cs/kg. (In a Danish diet meat comprises 2/3 pork and 1/3 beef).

5.9.9. Fish

The ^{90}Sr and ^{137}Cs contents in fish are estimted from table 5.8.2 at 0.5 pCi ^{90}Sr/kg and 59 pCi ^{137}Cs/kg.

5.9.10. Eggs

The activity contents in eggs were estimated from a 1975 sample collected in Copenhagen. The levels were 0.9 pCi ^{90}Sr/kg and 2.7 pCi ^{137}Cs/kg.

5.9.11. Coffee and Tea

One third of the total consumption consists of tea and two thirds of coffee. The mean contents from table 5.8.3 were used: 7.3 pCi ^{90}Sr/kg and 35.7 pCi ^{137}Cs/kg.

5.9.12. Drinking Water

The ^{90}Sr level (population-weighted mean) found in drinking water collected in June 1973 was used as the mean level for drinking water, i.e. 0.02 pCi ^{90}Sr/l. The ^{137}Cs content in drinking water is assumed to be negligible, because it cannot be detected even in surface fresh water (cf. 4.4).

5.9.13. Discussion

Tables 5.9.3 and 5.9.4 show the estimates of ^{90}Sr and ^{137}Cs in the Danish diet in 1976. The figures should be compared with the levels calculated from the total-diet samples (cf. 5.7). The ^{90}Sr estimates obtained by the two methods were 3.9 S.U. and 4.0 S.U. respectively, and the ^{137}Cs estimates were 11 pCi ^{137}Cs/day and 10 pCi ^{137}Cs/day.

The relative contributions of ^{90}Sr from milk products ($\sim$ 39%) and from grain (36%) were similar to those in 1975. The contribution from potatoes, other vegetables, and fruit was $\sim$ 22%, i.e. also nearly unchanged from 1975. The relative contribution of ^{137}Cs in the total diet changed as follows from 1975 to 1976: milk products were a little higher (16 to 18%), grain products decreased from 31 to 18%, and meat was higher (25 to 34%). Fish contributed nearly 16% to the total ^{137}Cs intake in 1976.

6. STRONTIUM-90 AND CAESIUM-137 IN MAN IN 1976

6.1. Strontium-90 in Human Bone

The collection of human vertebrae from the institutes of forensic medicine in Copenhagen and Århus was continued in 1976. As in the total-food survey (cf. 5.7), the country was divided

Table 6.1.1

Strontium-90 in bone from new-born children (< 1 month old) in 1976

Zone	Age in days	Month of death	Sex	pCi ^{90}Sr (g Ca)$^{-1}$
VI	2	3	F	1.20 A
VI	∿ 30	∿ 5	F	0.85*
*3 samples combined in one analysis.				

Table 6.1.2

Strontium-90 in bone from infants (≤ 4 years old) in 1976

Zone	Age in years and months	Month of death	Sex	pCi ^{90}Sr (g Ca)$^{-1}$
II	4 m	8	M	1.48
VI	1 y	4	M	1.00 A
VI	4 m	9	F	1.01
VI	4 y	10	F	1.0 B
VI	∿ 4 m	∿ 4	F	1.24*
VI	∿ 2 m	∿ 5	F	1.09*
VI	∿ 6 m	∿ 6	F	1.15**
VI	∿ 3 m	∿10	F	0.93**

* 4 samples combined in one analysis

**2 samples combined in one analysis

into eight zones. The samples were divided into five age groups: new-born (< 1 month), infants (1 month-4 years), children and teenagers (5 - 19 years), adults (≤ 29 years) and adults (> 29 years).

Tables 6.1.1 - 6.1 5 show the results for the five groups.

The levels were on the average two-thirds of those in 1975. The highest mean level in vertebrae was found in infants, but the levels in the different age groups were not much different.

Table 6.1.3

Strontium-90 in bone from children and teenagers (≤ 19 years) in 1976

Zone	Age in years	Month of death	Sex	pCi ^{90}Sr (g Ca)$^{-1}$
I	11	7	M	1.12
II	17	9	F	0.71
II	5	8	M	1.40
II	17	8	M	1.26
II	8	9	M	1.04
III	18	6	M	0.91
VI	9	2	F	0.4 B
VI	18	10	F	1.5 B
VI	14	2	F	0.86
VI	14	2	F	1.28
VI	19	10	F	0.54
VI	17	2	M	0.94
VI	14	2	M	0.84
VI	19	3	M	0.74
VI	15	10	M	0.93
VI	15	10	M	1.2 B
VI	9	3	M	1.03
VI	15	2	M	1.2 B
VI	18	4	M	0.51
VI	15	5	M	0.66
VI	18	4	M	0.84
VI	9	4	M	1.30 A
VI	17	11	M	0.94
VI	16	11	M	0.90
VI	15	11	M	0.74

Table 6.1.4

Strontium-90 in vertebrae from adults ($\leq$ 29 years) in 1976

Zone	Age in years	Month of death	Sex	pCi ^{90}Sr (g Ca)$^{-1}$
I	26	8	M	0.66
II	21	9	M	1.17
II	29	9	M	0.82
II	23	9	M	0.77
II	25	6	M	1.02
II	22	8	M	0.87
III	20	6	M	1.08
III	27	8	M	0.79
VI	23	10	F	1.42
VI	23	10	F	1.01
VI	22	9	F	0.70
VI	22	5	F	0.86
VI	22	11	F	0.85 A
VI	23	11	F	0.64
VI	24	1	M	1.16 A
VI	25	1	M	1.99
VI	26	1	M	1.42
VI	26	1	M	1.42
VI	20	3	M	1.62 A
VI	27	2	M	0.88
VI	23	3	M	0.93
VI	25	2	M	1.21
VI	29	2	M	1.29
VI	26	3	M	0.77
VI	24	4	M	0.98 A

Table 6.1.5

Strontium-90 in vertebrae from adults (> 29 years old) in 1976

Zone	Age in years	Month of death	Sex	pCi ^{90}Sr (g Ca)$^{-1}$
I	42	9	F	0.80
I	51	6	M	0.78
I	83	3	M	1.43
II	45	5	F	0.51
II	38	8	F	0.77
II	54	6	F	0.81
II	69	8	F	0.8 B
II	63	7	M	1.26
II	37	7	M	2.39
II	47	7	M	1.03
II	44	8	M	1.01
II	68	6	M	1.66
II	30	8	M	0.85
II	41	8	M	0.58
II	96	8	M	1.21
III	67	5	F	0.95
III	40	9	F	1.10
III	31	8	F	1.05
III	57	9	M	1.00
IV	47	7	F	0.92
V	79	7	F	0.90
VI	36	2	F	1.52 A
VI	35	2	F	0.75
VI	39	2	F	0.65
VI	30	5	F	0.85 A
VI	34	5	F	0.84

Table 6.1.6

Strontium-90 (pCi (g Ca)$^{-1}$) in human vertebrae collected in Denmark in 1976

Age group	Number of samples	Number of analysis	Min.	Max.	Median	Mean of analysis	Sample number weighted mean
New-born (< 1 month)	4	2	0.85	1.20	1.03	1.03	0.94
Infants (≤ 4 years)	16	8	0.93	1.48	1.07	1.12	1.13
Children (≤ 19 years)	25	25	0.39	1.48	0.93	0.95	0.95
Adults (≤ 29 years)	25	25	0.64	1.99	0.98	1.05	1.05
Adults (≥ 30 years)	26	26	0.51	2.39	0.91	1.01	1.01

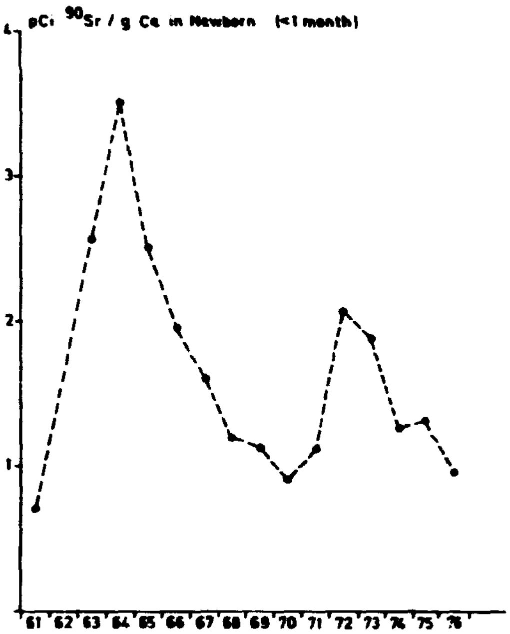

Fig. 6.1.1. Strontium-90 in bone from newborn 1961-76.

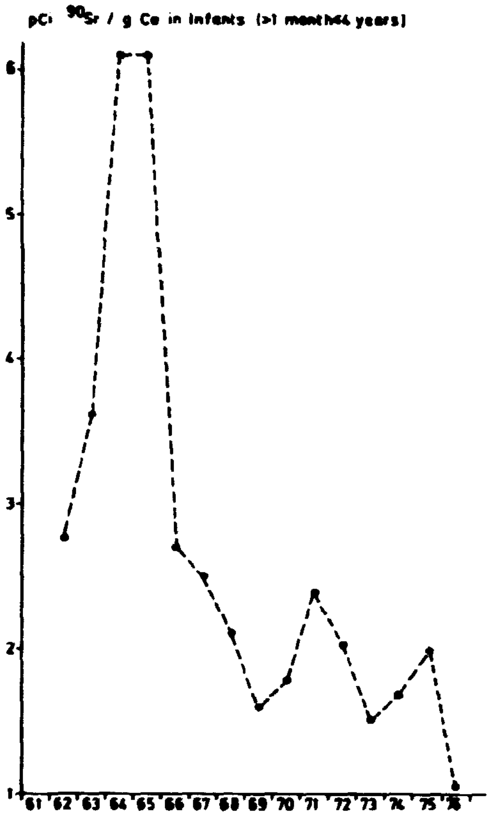

Fig. 6.1.2. Strontium-90 in bone from infants 1962-76.

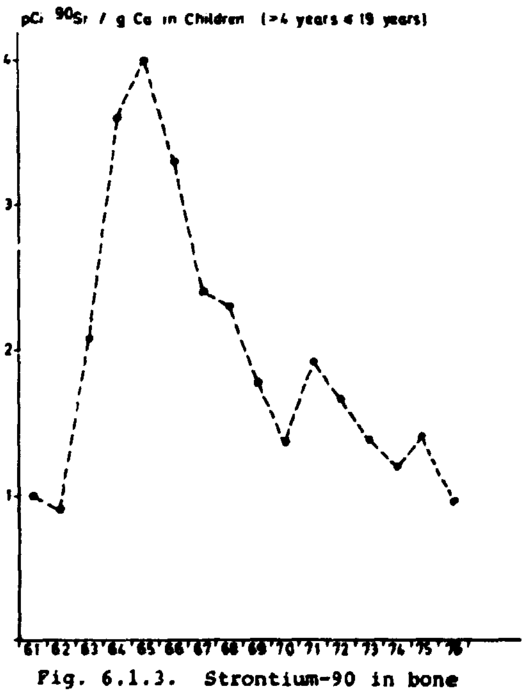

Fig. 6.1.3. Strontium-90 in bone from children 1961-76.

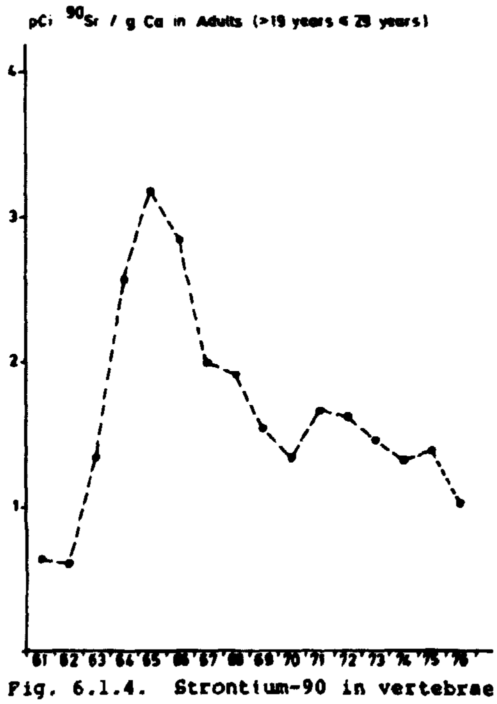

Fig. 6.1.4. Strontium-90 in vertebrae from adults ≤ 28 y,1961-76.

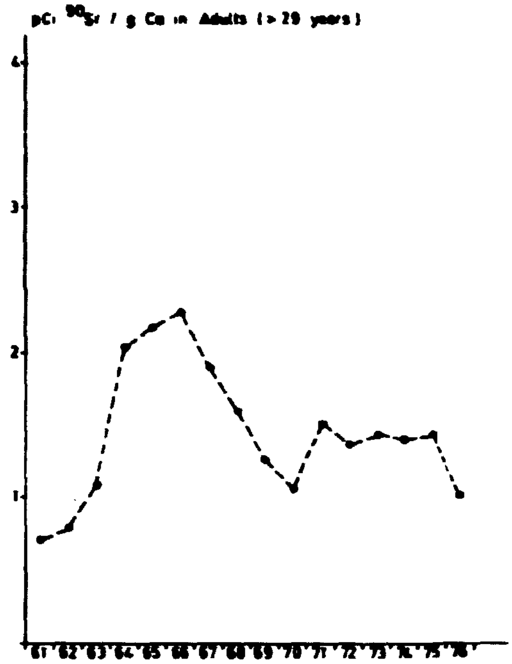

Fig. 6.1.5. Strontium-90 in vertebrae from adults > 29 y,1961-76.

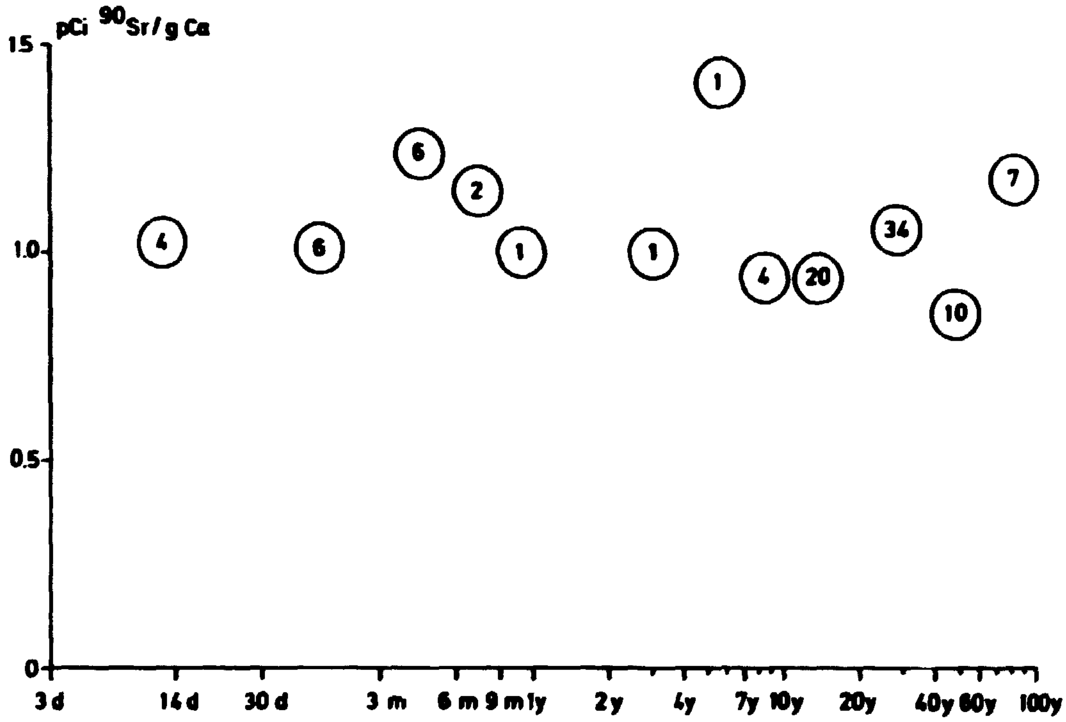

Fig. 6.1.6. Strontium-90 in human vertebrae in 1976 (the figures in the circles indicate the number of samples).

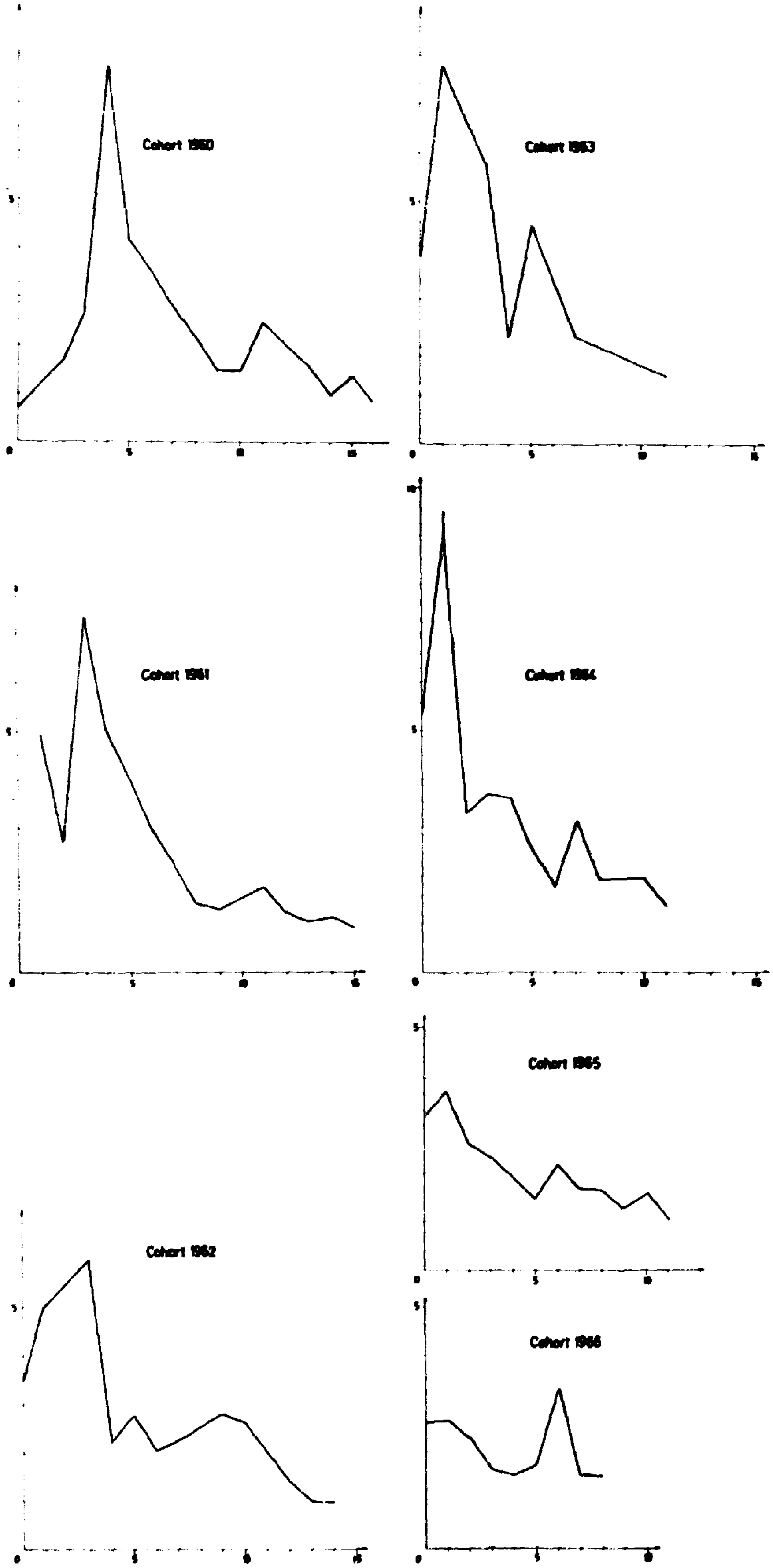

Fig. 6.1.7. Strontium-90 in human bone from Danish cohorts 1960-67 (Abscissa: age in years. Ordinate: bone level in pCi ^{90}Sr/g Ca).

6.2. Caesium-137 in the Human Body

Whole-body measurements were initiated at Risø in July 1963 (cf. 2.3 in Risø Report No. 85[1]). A control group from the Health Physics Department was selected and has since then been measured as far as possible three times a year. Table 6.2 shows the results.

The annual mean value of the control group was 9.5 pCi ^{137}Cs/g K. As earlier, we shall consider this figure representative of the mean of the Danish population in 1976. The total-body content of ^{137}Cs in 1976 for a standard man containing 140 g of potassium equals $140 \cdot 9.5 \cdot 10^{-3}$ nCi = 1.3 nCi ^{137}Cs, i.e. approx. 80% of the 1975 level.

Figure 6.2 shows the mean M.U. values (with one S.E.) for men and women measured in 1963-1976.

The maximum was reached in August 1964. The figure also shows that the mean level in the male group was approx. 1.3-1.5 times as high as that in the female group.

Table 6.2

Whole-body measurements of caesium-137 and potassium in 1976

No.	Sex	Counting date	Age	Height in cm	Weight in kg	M.U. in body	pCi ^{137}Cs kg^{-1}	g K kg^{-1} body weight
2	F	April	28	165	52	14.6	21	1.5
4	F	-	52	161	59	10.1	13.8	1.4
7	F	-	48	171	63	(2.5)	(3.0)	1.2
8	M	-	44	193	76	40	70	1.7
10	M	-	24	170	64	14.4	26	1.8
11	M	-	28	172	74	10.1	18.8	1.9
12	M	-	38	174	80	2.4 B	3.5 B	1.4
15	F	-	40	165	52	(2.5)	(3.5)	1.4
18	M	-	37	178	80	6.3	9.9	1.6
20	M	-	43	172	69	7.8	12.8	1.6
22	M	-	53	183	72	2.5 B	4.2 B	1.7
27	M	-	19	170	63	1.4 B	2.4 B	1.7
30	M	-	30	168	61	2.9 B	4.8 B	1.6
33	M	-	44	184	62	12.1	24	2.0
35	M	-	34	181	74	1.7 B	2.8 B	1.6
39	F	-	27	172	64	(2.5)	(3.0)	1.2
43	M	-	54	167	69	21	34	1.6
44	F	-	26	170	54	36 B	52 B	1.4
48	F	-	37	162	51	12.8	16.8	1.3
57	M	-	26	187	78	3.1 B	5.4 B	1.7
59	M	-	29	190	82	2.0 B	3.3 B	1.7
62	M	-	41	173	71	7.6 A	12.6 A	1.7
2	F	Aug	27	165	52	9.1	15.0	1.7
7	F	-	47	171	63	9.1 A	14.2 A	1.6
8	M	-	44	193	78	20	38	1.9
10	M	-	23	171	63	12.3	24	2.0
19	M	-	33	174	69	10.3	19.4	1.9
20	M	-	43	172	69	13.4	22	1.6
22	M	-	52	183	72	11.9	23	1.9
23	M	-	45	192	87	2.7 B	4.9 B	1.8
24	M	-	44	170	75	7.6 A	14.7 A	1.9
26	F	-	36	160	54	18.3	24	1.3
30	M	-	30	168	60	9.7	17.8	1.8
32	F	-	47	157	62	16.4	26	1.6
33	M	-	44	184	62	28	57	2.0
35	M	-	34	181	75	17.4	33	1.9
43	M	-	64	167	68	7.2 A	13.6 A	1.9
44	F	-	26	170	53	15.5	23	1.5
48	F	-	39	162	50	12.0	17.7	1.5
50	M	-	28	169	67	34	60	1.8
51	M	-	44	175	89	14.2	27	1.9
54	F	-	35	163	60	15.8	20	1.3
60	F	-	38	164	83	16.7	21	1.3
61	F	-	32	158	43	17.8	26	1.5
62	M	-	40	173	68	13.0	21	1.8
2	F	Dec	28	165	52	(2.5)	(3.5)	1.4
7	F	-	48	171	64	14.3	17.1	1.2
8	M	-	44	193	79	(2.5)	(6.5)	1.8
10	M	-	24	171	63	(2.5)	(3.8)	1.5
12	M	-	38	174	81	(2.5)	(4.2)	1.7
19	M	-	33	174	71	(2.5)	(4.5)	1.8
20	M	-	44	172	69	(2.5)	(4.0)	1.6
22	M	-	53	183	72	(2.5)	(4.5)	1.8
23	M	-	46	192	86	(2.5)	(4.0)	1.6
24	M	-	45	170	61	(2.5)	(3.8)	1.5
25	F	-	34	167	56	34	41	1.2
30	M	-	30	168	62	(2.5)	(4.0)	1.6
32	F	-	47	157	61	(2.5)	(3.0)	1.2
34	M	-	36	177	70	(2.5)	(4.0)	1.6
35	M	-	35	181	76	(2.5)	(4.2)	1.7
39	F	-	27	172	66	(2.5)	(3.5)	1.4
43	M	-	59	167	69	(2.5)	(4.0)	1.6
48	F	-	37	162	50	(2.5)	(3.5)	1.4
53	F	-	50	154	99	(2.5)	(2.2)	0.9
54	F	-	36	163	62	(2.5)	(2.5)	1.0
57	M	-	27	187	80	(2.5)	(4.5)	1.8
59	M	-	29	190	84	(2.5)	(4.0)	1.6
61	F	-	33	158	44	(2.5)	(3.2)	1.3
63	F	-	48	166	73	3.7 B	4.0 B	1.1

Figures in brackets relate to results below detection limit. They were estimated at half of detection limit.

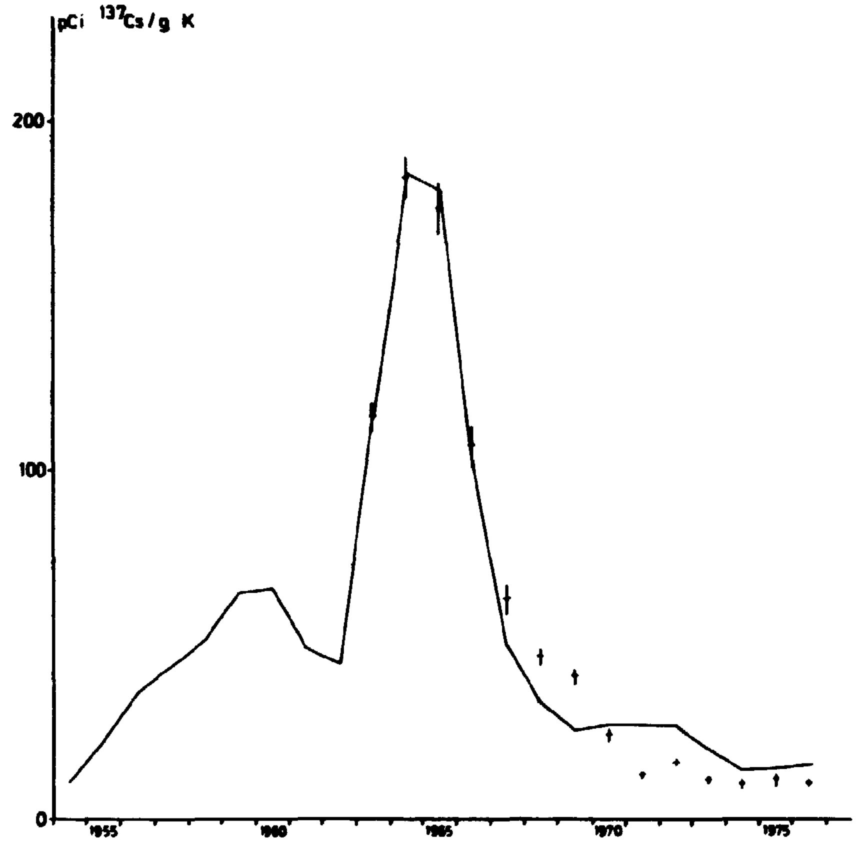

Fig. 6.2. A comparison between observed (± 1 S.E.) and calculated (curve, cf. appendix C) pCi $^{137}Cs/gK$ levels in whole-body from the Islands.

7. STRONTIUM-90 AND CAESIUM-137 IN SEAWATER IN 1976

As in previous years, seawater samples were collected by M/S Fyrholm in the summer and late autumn from inner Danish Waters (cf. table 7.1 and figs. 7.1 and 7.2). Furthermore, seawater samples were collected at Barsebäck in the Sound (table 7.2), and at Ringhals in the Kattegat (table 7.3). The DANA took samples in the North Sea and the Skagerak in February and in June (table 7.4).

In Risø Report No. 305[1] it was suggested that the increasing ^{90}Sr and ^{137}Cs levels observed in 1973 in inner Danish waters were due to contamination from inflow of water from the North Sea contaminated with ^{137}Cs and ^{90}Sr from nuclear plants in the UK and France.

In accordance with this hypothesis, the ^{90}Sr concentration increased especially in seawater of high salinity as shown in the following regression equations:

$$\text{pCi } ^{90}\text{Sr l}^{-1} = 0.94 - 0.018 \text{ o/oo} \quad (1967\text{-}71)$$
$$\text{pCi } ^{90}\text{Sr l}^{-1} = 0.97 - 0.020 \text{ o/oo} \quad (1972)$$
$$\text{pCi } ^{90}\text{Sr l}^{-1} = 0.95 - 0.014 \text{ o/oo} \quad (1973)$$
$$\text{pCi } ^{90}\text{Sr l}^{-1} = 0.93 - 0.010 \text{ o/oo} \quad (1974)$$
$$\text{pCi } ^{90}\text{Sr l}^{-1} = 0.79 - 0.006 \text{ o/oo} \quad (1975)$$
$$\text{pCi } ^{90}\text{Sr l}^{-1} = 0.71 - 0.002 \text{ o/oo} \quad (1976)$$

(The regression analysis showed significant or probably significant regression in all cases except in 1973, 1975 and 1976).

Table 7.1

Strontium-90 in sea water collected around Zealand in June and November 1976

	Position		June				November			
	N	E	depth in m	^{90}Sr pCi l^{-1}	Salinity o/oo	^{137}Cs pCi l^{-1}	depth in m	^{90}Sr pCi l^{-1}	Salinity o/oo	^{137}Cs pCi l^{-1}
Kullen	56°15'	12°25'	0	0.64	18.5	0.82	0		29.9	1.25
"			22		31.2	1.02	23	0.49	34.3	1.38
Hesselø	56°10'	11°47'	0	0.70	18.2	0.77	0	0.68	23.6	1.18
"			22	0.43	33.4	0.96	25		29.3	1.67
Kattegat SW	56°07'	11°10'	0	0.66	15.1	0.87				
"			36		33.0	0.94				
Asnæs reef	55°38'	10°47'	0		18.0	0.95	0	0.68	24.3	1.16
" "			46	0.52	32.1	1.24	42		30.7	1.38
Halskov reef	55°20'	11°02'	0		14.6	0.88	0	0.75	25.8	0.94
" "			45		32.0	1.20	49	0.66	29.3	1.31
Langeland belt	54°52'	10°50'	0		12.6	0.80	0	lost	25.5	0.96
" "			47		30.2	1.51	50	0.83	33.7	1.05
Fehmern belt	54°36'	11°05'	0		10.3	0.79	0	0.75	19.9	0.80
" "			30		28.0	0.89	24	lost	24.5	1.56
Gedser reef	54°28'	12°13'	0		9.8	0.61	0	0.88	13.9	0.46
" "			26	0.62	17.8	0.81	23		31.6	0.94
Møen	54°57'	12°41'	0	0.68	8.1	0.72				
"			20		13.4	0.80	20	0.80	lost	1.03
The Sound - south	55°25'	12°39'	0	0.67	7.9	0.55	0		25.7	0.62
" " "			12		9.1	0.55	12	0.66	21.8	1.08
The Sound - north A	55°48'	12°44'	0	0.46	19.9	0.94	0		11.7	0.53
" " "			20		35.4	0.76	19	0.59	31.5	1.27
The Sound - north B	55°59'	12°42'	0		19.2	0.99	0	0.66	22.9	0.80
" " "			27	0.47	32.3	1.20	27	0.54	32.7	1.32
Mean			Surface	0.64	14.4	0.81	Surface	0.73	22.3	0.87
SD				0.09	4.5	0.13		0.08	5.6	0.28
SE				0.04	1.3	0.04		0.03	1.8	0.09
Mean			Bottom	0.51	27.3	0.99	Bottom	0.65	29.9	1.27
SD				0.08	8.8	0.26		0.13	4.0	0.2[illegible]
SE				0.04	2.5	0.08		0.05	1.3	0.07

Table 7.2

Strontium-90 and Caesium-137 in sea water collected in the Sound (Barsebäck) in 1976

Position		June				December		
N	E	depth in m	^{90}Sr pCi l^{-1}	^{137}Cs pCi l^{-1}	Salinity o/oo	depth in m	^{137}Cs pCi l^{-1}	Salinity o/oo
55°42'08"	12°54'	0	0.55	0.71	19.1	0	0.69	11.8
-"-	-"-	14.5	0.51	1.03	24.1	14	1.13	18.8
55°47'05"	12°51'07"	0	0.63	1.22	19.9	0	0.81	lost
-"-	-"-	16	0.59	1.13	26.0	15	1.23	27.7
Mean		Surface	0.59	0.97	19.5	Surface	0.75	11.8
SD			0.06	0.36	0.6		0.08	
SE			0.04	0.26	0.4		0.06	
Mean		Bottom	0.55	1.08	25.0	Bottom	1.18	23.2
SD			0.06	0.07	1.3		0.07	6.3
SE			0.04	0.05	1.0		0.05	4.4

Table 7.3

Strontium-90 and Caesium-137 in sea water collected at Ringhals in July 1976

Position		depth in m	^{90}Sr pCi l^{-1}	^{137}Cs pCi l^{-1}	Salinity o/oo
N	E				
57°16'05"	12°06'	0	0.71	0.90	20.7
- " -	- " -	15	0.65	1.05	35.9
57°13'03"	12°03'04"	0	0.71	0.91	28.3
- " -	- " -	24	0.84	1.16	31.6
57°14'	11°53'06"	0	0.68	0.96	10.7
- " -	- " -	74	0.93	0.90	33.2
Mean		Surface	0.70	0.92	19.9
S.D.			0.02	0.03	8.8
S.E.			0.01	0.02	5.1
Mean		Bottom	0.81	1.04	33.6
S.D.			0.14	0.13	2.2
S.E.			0.08	0.08	1.2

Table 7.4

Strontium-90 and Caesium-137 in sea water collected at the North Sea in 1976

Position	Date	^{90}Sr pCi l^{-1}	^{137}Cs pCi l^{-1}	Salinity o/oo
57°30'N 08°00'E	Feb 2	0.44	0.77	34.0
61°03'N 01°05'W	-	0.12	0.25	34.9
59°32'N 00°44'E	-	0.32	1.64	34.6
59°21'N 02°57'E	-	0.18	0.57	34.9
54°18'N 07°44'E	-	0.66	1.14	31.1
55°18'N 05°00'E	-	0.96	1.78	34.6
59°51'N 03°28'E	June 21	0.13	0.50	34.5
56°42'N 06°43'E	June 18	0.66	1.60	33.2
56°37'N 04°35'E	June 19	0.44	1.37	34.3
56°15'N 05°30'E	June 19	0.80	1.32	34.1
56°15'N 07°30'E	June 17	0.78	1.41	33.7
57°14'N 01°54'E	June 20	0.43	1.57	35.0
Mean		0.49	1.16	34.1
S.D.		0.28	0.51	1.1
S.E.		0.08	0.15	0.3

In analogy with ^{90}Sr, the following regression equations were found for ^{137}Cs in inner Danish waters:

$$\text{pCi } ^{137}\text{Cs } l^{-1} = 0.80 - 0.0043 \text{ o/oo} \quad (1972)$$
$$\text{pCi } ^{137}\text{Cs } l^{-1} = 0.60 + 0.012 \text{ o/oo} \quad (1973)$$
$$\text{pCi } ^{137}\text{Cs } l^{-1} = 0.54 + 0.018 \text{ o/oo} \quad (1974)$$
$$\text{pCi } ^{137}\text{Cs } l^{-1} = 0.64 + 0.010 \text{ o/oo} \quad (1975)$$
$$\text{pCi } ^{137}\text{Cs } l^{-1} = 0.53 + 0.019 \text{ o/oo} \quad (1976)$$

(The regression analysis showed a significant regression in 1974 and 1976, probably significant in 1973 and 1975, and insignificant in 1972).

According to the above regression lines, the mean levels in Danish surface waters (16 o/oo salinity) have been relatively constant since 1972. The mean ^{90}Sr concentration was estimated at 0.70 $\pm$ 0.05 (1SD) pCi l^{-1} and the ^{137}Cs level was 0.80 $\pm$ 0.04 pCi l^{-1}.

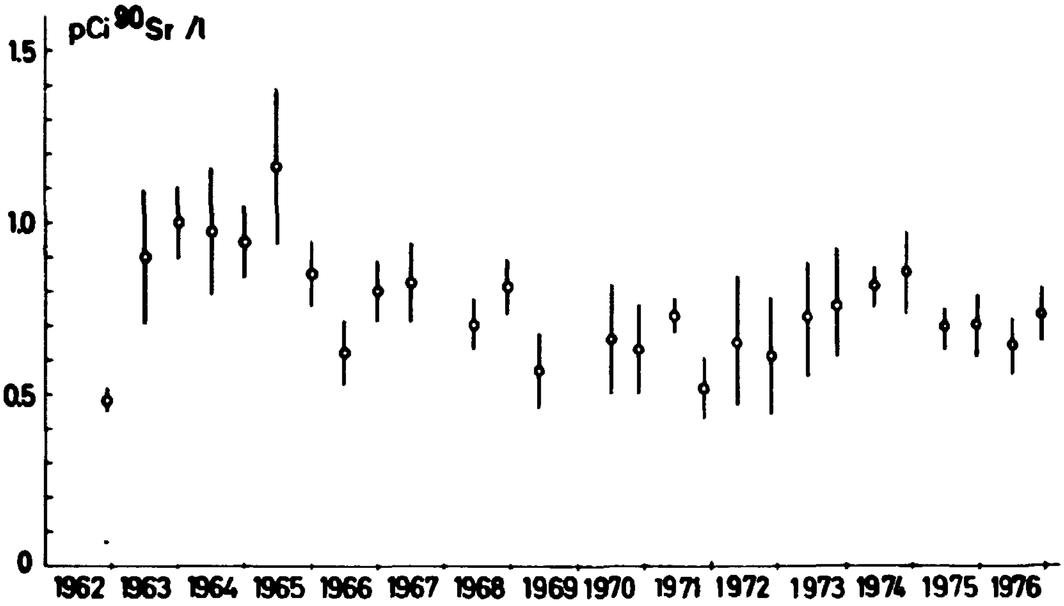

Fig. 7.1. Strontium-90 in surface sea-water from inner Danish waters, 1962-76 (1 S.D. indicated) (from table 7.1).

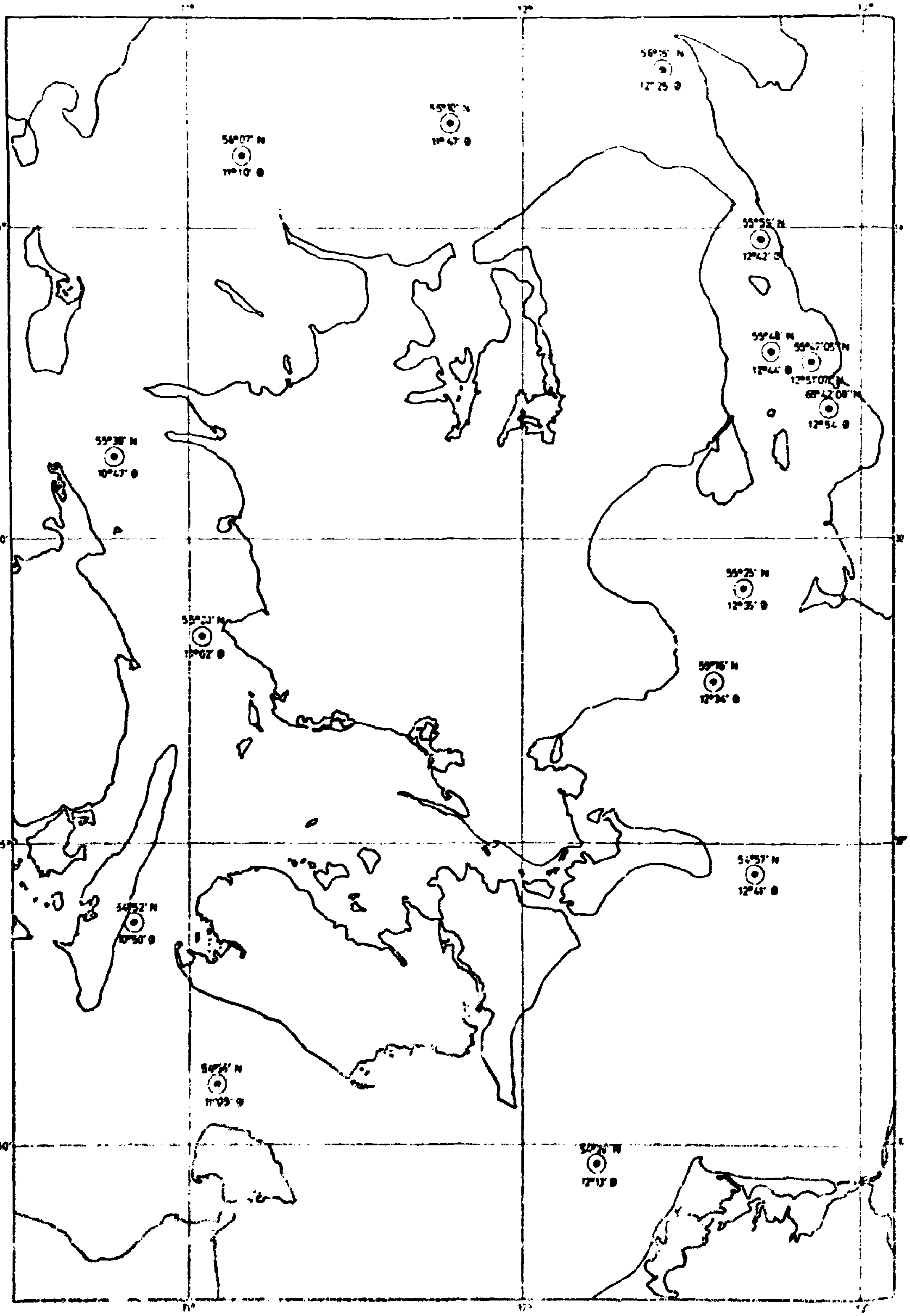

Fig. 7.2. Sea-water locations around Zealand.

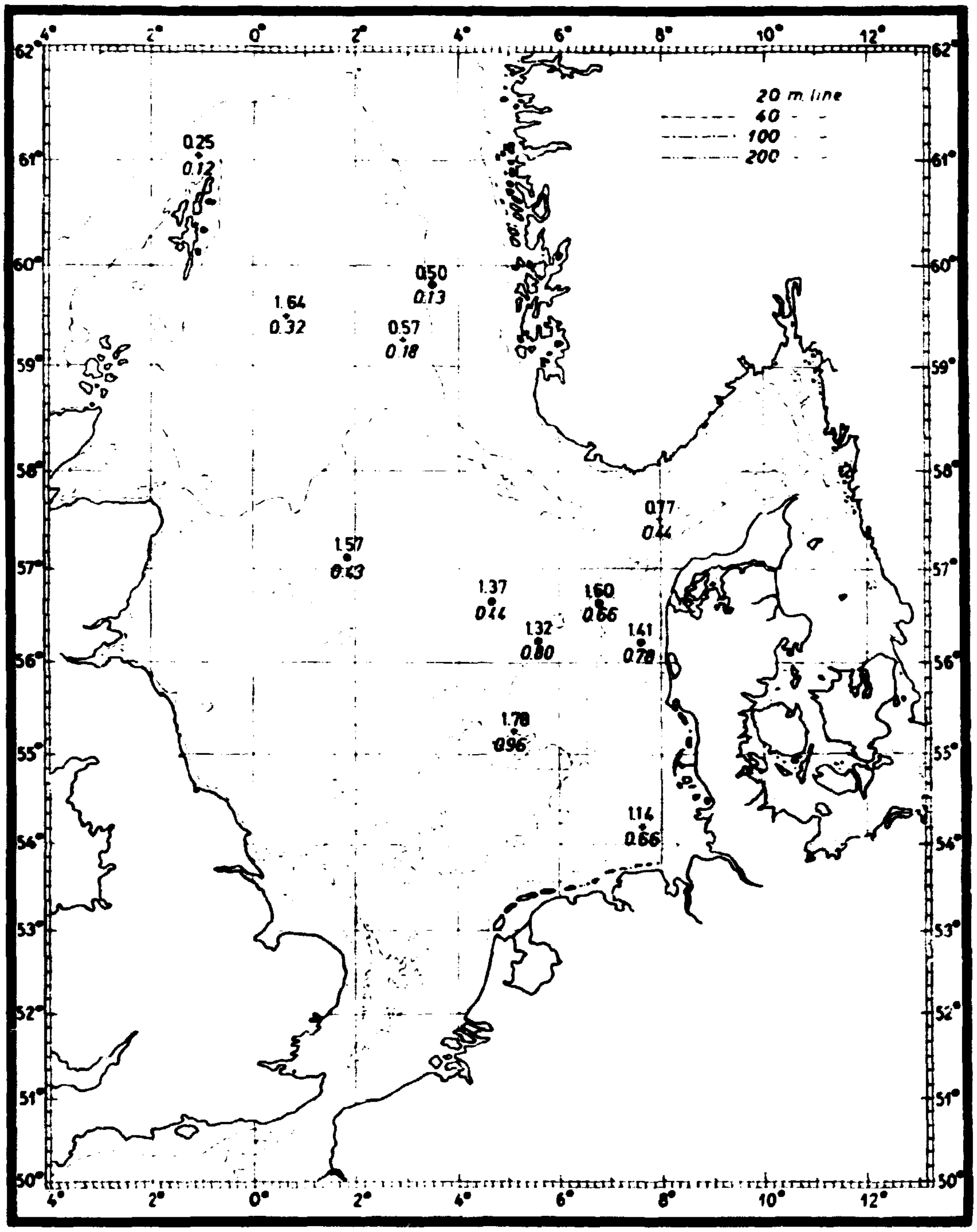

Fig. 7.5. Concentrations (pCi/l) of ^{137}Cs and ^{90}Sr (italics) in surface sea-water collected in February (+) and June (●) 1976.

8. SPECIAL SURVEYS

8.1. Meteorclogical Mast Experiments

No samples were collected in 1976.

8.2. Fission Product Ratios in Air Samples Collected at Different Heights in the Meteorological Mast

No samples were collected in 1976.

8.3. Human Milk

No human milk samples were collected in 1976.

8.4. Country-wide Measurement of the γ-Background in 1976

8.4.1. State Experimental Farms

As in previous years[1], the γ-background was measured at the State experimental farms (cf. fig. 4.1.1). Table 8.4.1.1 shows the results, and table 8.4.1.2 gives the analysis of variance. The variation between locations was highly significant ($P > 99.95\%$). As previously, it was evidently not the fall-out that determined the variation between locations. The mean level in 1976 was lower than the 1975 level.

Fig. 8.4 shows the γ-background since 1962 in four groups of sampling stations. The fact that stations with a low fall-out rate and a high clay content in the soil (Abed, Blangstedgård, and Tystofte) show higher γ-levels than stations with a high fall-out rate and a low clay content (but a high sand content) (Studsgård, St. Jyndevand, and Askov) was discussed in Risø Report No. 154[1].

Table 8.4.1.1

γ-background at the state experimental farms in 1976 (μR/h)

	June-July	October	December	Mean
Tylstrup	5.2	4.7	5.6	5.2
Studsgård	4.3	4.2	4.4	4.3
Ødum	6.3	5.7	6.0	6.0
Askov	5.3	5.8	5.3	5.5
St. Jyndevad	3.8	5.5	4.6	4.6
Blangstedgård	6.2	5.5	5.8	5.8
Tystofte	5.8	7.4	7.4	6.9
Virumgård	5.1	5.5	5.9	5.5
Ledreborg	5.2	[illegible]	5.7	5.6
Abed	5.1	6.4	6.4	6.0
Tornbygård	(6.4)	6.8	(6.9)	(6.7)
Mean	(5.3)	5.8	(5.8)	5.6

Table 8.4.1.2

Analysis of variance of the γ-background
at the state experimental farms in 1976
(from table 8.4.1.1)

Variation	SSD	f	s^2	v^2	P
Between locations	92.948	10	9.295	6.289	> 99.95%
Between months	7.265	2	3.633	2.458	-
Loc. x months	26.602	18	1.478	12.546	> 99.95%
Remainder	17.199	146	0.118		

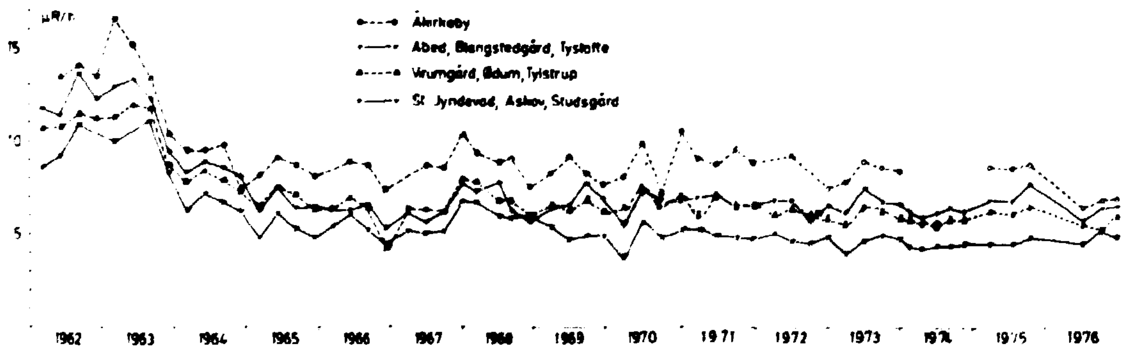

Fig. 8.4. The γ-background at the State experimental farms, 1962-76.

8.4.2. The Risø Environment

Gamma background measurements were performed in the five zones round Risø. The measurements were carried out at the locations where grass is collected (cf. figs. 3.1.2.1 and 3.1.2.2 (the coloured map)).

Tables 8.4.2.1 and 8.4.2.2 show the results.

At all locations in zone I, especially at the waste treatment station (location 3), the γ-background showed increased levels because of the various radiation sources at the research establishment. The weighted annual mean for zones III-V was 5.9 μR/h. In zone I the excess activity from the research establishment was 17.8 - 5.9 = 11.9 μR/h (in 1967: 4.0, in 1968: 3.9, in 1969: 3.3, in 1970: 4.7, in 1971: 1.6, in 1973: 11.5 in 1974: 16.0 and in 1975: 21.2 μR/h). A man working in the open in the Risø area 40 hours a week for 45 weeks a year would thus get an excess dose of 21 mR/year.

Table 8.4.2.1

γ-background (μR/h) in Zone I around Risø in 1976

Location	Feb 2	July 1	Aug 2	Sept 1	Oct 1	Oct 29	Nov 29	Mean
1	5.8	5.6	6.1	5.9	6.0	5.9	5.9	5.9
2	8.0	7.0	6.8	7.3	7.3	6.7	7.9	7.3
3	78.4	66.3	61.0	63.3	26.1	44.5	44.7	54.9
4	7.4	6.4	6.2	6.6	6.4	6.3	6.4	6.5
5	14.9	15.5	14.4	15.3	13.3	13.2	13.2	14.3
Mean	22.9	20.1	18.9	19.7	11.8	15.3	15.6	17.8

Table 8.4.2.2

γ-background (μR/h) in four zones (II-V) around Risø in 1976

*Risø zone	Location	Jan	Feb	July	Aug	Oct	Nov	Mean
II	1		6.6	5.3	5.2	5.1	5.6	5.6
-	2		7.2	6.0	6.0	6.0	6.2	6.3
-	3		6.2	5.0	4.9	4.9	5.2	5.3
-	4		6.6	5.5	5.8	5.7	6.1	5.9
Mean			6.6	5.4	5.5	5.4	5.8	5.7
III	1		7.4	6.3	6.8	6.9	7.2	6.9
-	2		7.0	5.7	5.8	5.7	5.8	6.0
-	3		6.6	5.2	5.3	5.2	5.9	5.6
Mean			7.0	5.7	6.0	5.9	6.3	6.2
IV	1	5.8		4.8		5.4		5.4
-	2	6.8		5.1		5.5		5.8
-	3	6.8		5.0		5.4		5.8
-	4	7.0		5.5		5.3		5.9
-	5	5.4		5.7		5.6		5.6
-	6	6.2		4.5		4.8		5.1
-	7	6.6		5.4		6.0		6.0
Mean		6.4		5.1		5.4		5.6
V	1	6.2		7.2		6.6		6.7
-	2	7.0		6.2		6.4		6.5
-	3	6.0		5.0		5.2		5.4
-	4	6.0		5.3		6.1		5.8
-	5	6.8		5.8		5.7		6.1
-	6	6.6		5.5		6.0		6.0
-	7	6.0		7.0		7.2		6.8
-	8	6.2		5.5		6.4		6.0
-	9	7.0		5.7		6.1		6.3
-	10	6.2		4.9		5.3		5.5
Mean		6.4		5.8		6.1		6.1

*(cf. coloured map in Risø report No. 323[1]).

8.5. Environmental Surveys at Barsebäck, Ringhals and in other Marine Environments

Sweden is operating nuclear power plants on the Sound at Barsebäck and on the Kattegat at Ringhals. At present two units

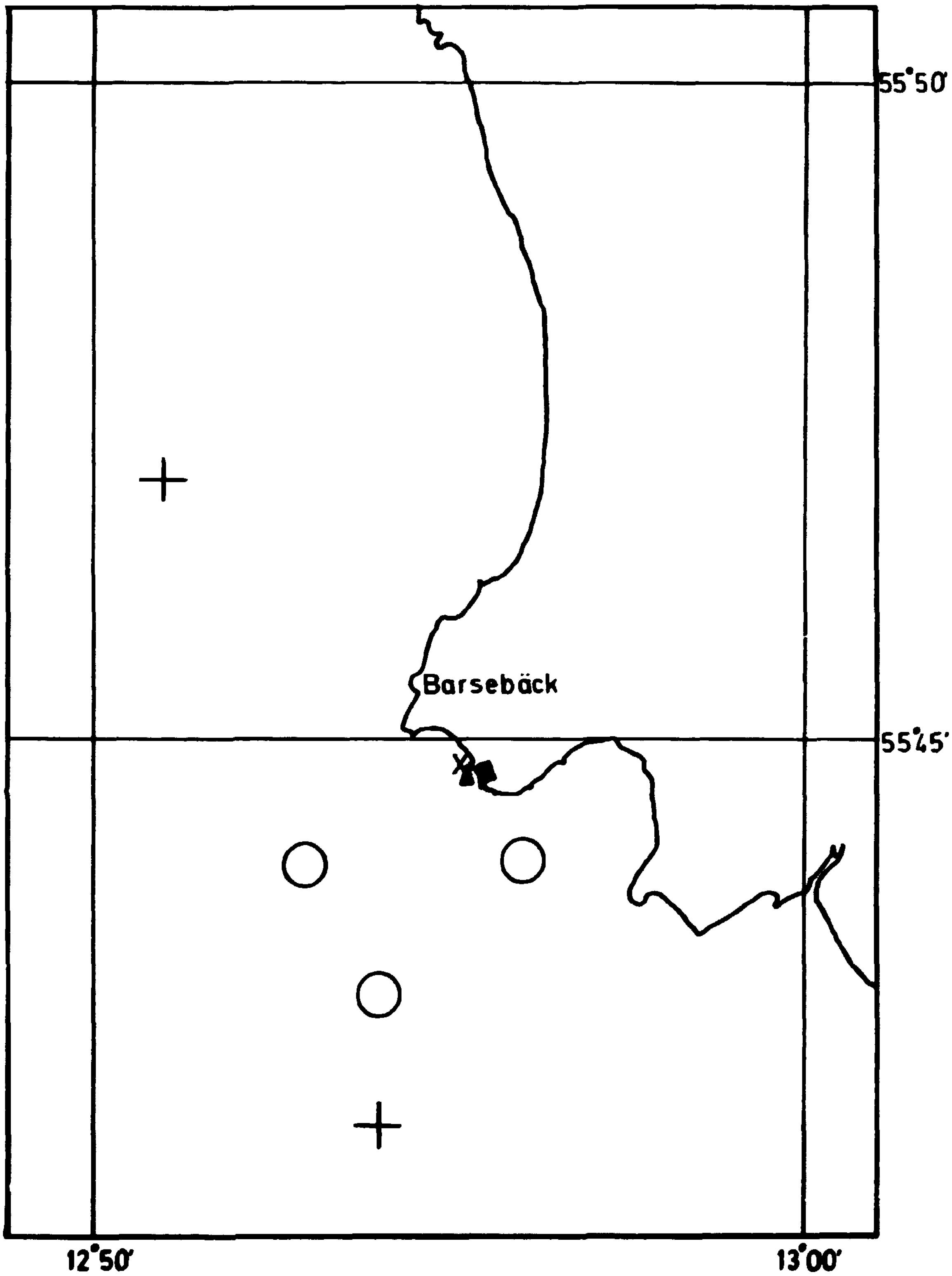

Fig. 8.5.1. Sampling locations for sea-water (+) bed soil (o), sea animals (x) and seaplants (Δ) at Barsebäck.

are in operation at each site. As both locations are close to Danish waters and fishing grounds, the marine environment around them is monitored by collection of seawater (table 7.2 and 7.3), sediments (8.5.1) and biological samples (8.5.2).

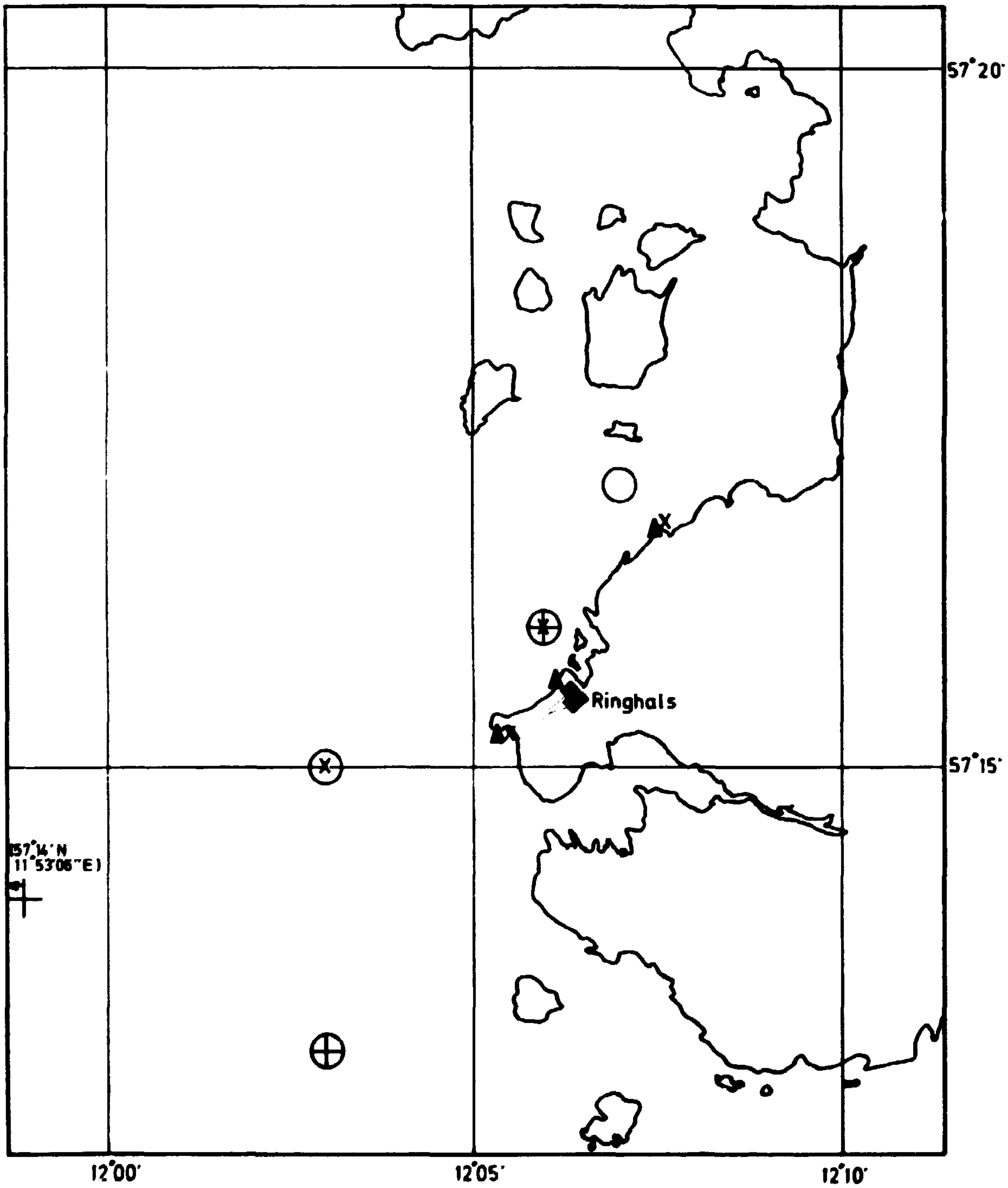

Fig. 8.5.2. Sampling locations for sea-water (+) bed soil (o), seaanimals (x) and seaplants (a) at Ringhals.

8.5.1. Sediment Samples

The sediments were taken by the HAPS sampler[18] and 3 cm thick sections were analysed to a depth of approx. 15 cm. Anova's (tables 8.5.1.3 and 8.5.1.5) showed that the ^{137}Cs levels were similar to those observed in 1975. The vertical distribution sometimes showed a maximum in the 3-6 cm layer, probably an indication of the 1962-63 fall-out peak. The integrated mean levels in the sediments were estimated at approx. 15 mCi km^{-2} at Barsebäck (tables 8.5.1.1-8.5.1.2). Sediments from Ringhals (table 8.5.1.4), the Great Belt (table 8.5.1.8) and the North Sea (table 8.5.1.9) showed similar, integrated ^{137}Cs levels. A few sediment samples (tables 8.5.1.1, 8.5.1.2 and 8.5.1.7) near Barsebäck contained traces of ^{54}Mn, ^{58}Co and ^{60}Co indicating releases of corrosion products from the plant.

Table 8.5.1.1

Caesium-137 in bed soil collected at Barsebäck in June 1976

Position	Depth in cm	pCi ^{137}Cs kg^{-1}	mCi ^{137}Cs km^{-2}	Traces
55°44'07"N 12°53'01"E	0-3	820	5.8	^{54}Mn
-"- -"-	3-6	162 A	1.7 A	
-"- -"-	6-9	130 A	1.0 A	
-"- -"-	9-12	B.D.L	B.D.L	
-"- -"-	12-15	B.D.L	B.D.L	
	0-15		Σ 8.5	
55°43'08"N 12°54'04"E	0-3	1091	6.4	
-"- -"-	3-6	460	4.3	
-"- -"-	6-9	90	1.2	
-"- -"-	9-12	107	1.5	
-"- -"-	12-15	13 B	0.2 B	
	0-15		Σ 13.6	
55°44'00"N 12°56'02"E	0-3	106	4.1	
-"- -"-	3-6	82	3.5	
-"- -"-	6-8	124	3.3	
	0-8		Σ 10.9	

Table 8.5.1.2

Caesium-137 in bed soil collected at Barsebäck in December 1976

Position	Depth in cm	pCi ^{137}Cs kg^{-1}	mCi ^{137}Cs km^{-2}	Traces
55°44'07"N 12°53'01"E	0-3	970	6.2	
- " - - " -	3-6	470	4.8	
- " - - " -	6-9	360	4.7	
- " - - " -	9-12	84	0.8	
	0-12		Σ 16.5	
55°43'08"N 12°54'04"E	0-3	1270	8.1	^{58}Co, ^{54}Mn, ^{60}Co*
- " - - " -	3-6	680	7.2	
- " - - " -	6-9	330	3.1	
- " - - " -	9-12	180	1.8	
- " - - " -	12-15	B.D.L	B.D.L	
	0-15		Σ 20.2	
55°44'00"N 12°56'02"E	0-3	790	2.7	^{60}Co
- " - - " -	3-6	940	7.4	
- " - - " -	6-9	110 A	1.3 A	
- " - - " -	9-12	75 B	1.0 B	
- " - - " -	12-15	156	2.2	
	0-15		Σ 14.6	

*Reference to table 8.5.1.4

Table 8.5.1.3

Analysis of variance of ln ^{137}Cs mCi km^{-2}
in bed soil from Barsebäck 1975-1976

Variation	SSD	f	s^2	v^2	P
Between month	3.885	3	1.295	3.583	-
Between depth	14.692	4	3.673	10.163	> 99.9%
Between location	0.816	3	0.272	2.442	-
Between month x depth	3.976	11	0.361	3.775	> 97.5%
Between depth x location	1.207	7	0.172	1.801	-
Between month x location	0.301	5	0.060	0.629	-
Between month x depth x loc.	1.053	11	0.096		

Table 8.5.1.4

Caesium-137 in bed soil collected at Ringhals in July 1976

Position	Depth in cm	pCi ^{137}Cs kg^{-1}	mCi ^{137}Cs km^{-2}
57°15'01"N 12°03'07"E	0-3	159	3.8
- " - - " -	3-6	103	3.7
- " - - " -	6-9	103	3.7
- " - - " -	9-12	36	1.46
- " - - " -	12-13	B.D.L	B.D.L
	0-13		Σ 12.7
57°16'05"N 12°06'03"E	0-3	101	3.0
- " - - " -	3-6	74	2.6
- " - - " -	6-9	26 B	0.92 B
- " - - " -	9-12	B.D.L	B.D.L
- " - - " -	12-13	B.D.L	B.D.L
	0-13		Σ 6.5
57°17'01"N 12°07'02"E	0-3	24 B	0.93 B
- " - - " -	3-6	73 A	2.74 A
- " - - " -	6-9	48 A	1.70 A
- " - - " -	9-12	58 A	1.38 A
	0-12		Σ 6.8
57°13'03"N 12°03'04"E	0-3	250	4.5
- " - - " -	3-6	190	6.2
- " - - " -	6-9	58	1.94
- " - - " -	9-12	63	2.2
- " - - " -	12-13	22 B	0.3 B
	0-13		Σ 15.1

Table 8.5.1.5

Analysis of variance of ln ^{137}Cs mCi km^{-2}
in bed soil from Ringhals 1975-1976

Variation	SSD	f	s^2	v^2	P
Between month	0.093	1	0.093	0.552	-
Between depth	1.988	3	0.663	3.943	> 97.5%
Between location	3.665	3	1.222	7.270	> 99.5%
Between month x depth	0.087	3	0.029	0.101	-
Between depth x location	0.930	8	0.116	0.404	-
Between month x location	0.327	3	0.109	0.378	-
Between month x depth x loc.	1.441	5	0.288		

Table 8.5.1.6

Caesium-137 in bed soil collected in the Sound in June 1976

Position	Depth in cm	pCi ^{137}Cs kg^{-1}	mCi ^{137}Cs km^{-2}	Traces
55°59'N 12°42'E	0-3	250	3.6	^{54}Mn
- " - - " -	3-6	220	4.1	
	0.6		Σ 7.7	

Table 8.5.1.7

Zink-65 and Cobalt-60 in bed soil (3-6 cm)
collected at Barsebäck in December 1976

Position	Isotope	pCi kg^{-1}	mCi km^{-2}
55°43'08"N 12°54'04"E	^{65}Zn	865	9.1
- " - - " -	^{60}Co	910±30	9.6±0.3

Table 8.5.1.8

Caesium-137 in bed soil collected in Great Belt in June 1976

Poisition	Depth in cm	pCi ^{137}Cs kg^{-1}	mCi ^{137}Cs km^{-2}
55°38'N 10°47'E	0-3	180	4.2
- " - - " -	3-6	139	3.8
	0-6		Σ 8.0
55°13'N 11°06'E	0-3	290	4.3
- " - - " -	3-6	340	5.5
- " - - " -	6-9	90	1.69
- " - - " -	9-10	91	0.33
	0-10		Σ 11.8

Table 8.5.1.9

Caesium-137 in bed soil collected in The North Sea in February 1976

Position	Depth in cm	pCi ^{137}Cs kg^{-1}	mCi ^{137}Cs km^{-2}
55°18'N 05°00'E	0-3	55	1.71
- " - - " -	3-6	87	3.8
	0-6		5.5
57°30'N 08°00'E	0-3	108	0.97
- " - - " -	3-6	140	3.4
- " - - " -	6-9	94	2.6
	0-9		7.0
60°15'N 00°30'E	0-3	200	3.0
- " - - " -	3-6	133	3.2
- " - - " -	6-9	189	4.8
- " - - " -	9-12	170	4.8
	0-12		15.8

8.5.2. Biological Samples

A sample of Fucus vesicolosus collected at Barsebäck in June 1976 contained corrosion products (table 8.5.2.2). The cobalt isotopes ^{58}Co and ^{60}Co were the most prominent, but ^{54}Mn and probably also ^{65}Zn were detectable too. A sample of Mytilus edulis contained traces of ^{60}Co (table 8.5.2.1).

The Ringhals samples from July 1976 (Mytilus and Fucus: table 8.5.2.3) also contained corrosion products. The levels did not present any health hazards. The annual dose to a hypothetically critical individual consuming 20 kg of Mytilus flesh annually would be less than 1 o/oo of the background radiation dose, i.e. < 0.1 mrem y^{-1} (wholebody dose), estimated from the present measurement.

Table 8.5.2.1

Caesium-137 in Mytilus Edulis collected at the outlet of Barsebäck in 1976

	^{137}Cs pCi kg^{-1}	M.J.	Traces
Meat	8.6 A	10.1 A	
Shells	1.5 B	0.2 B	
Total	14.0	19.5	^{60}Co

Table 8.5.2.2

Radionuclides in Fucus vesicolosus collected at the outlet of Barsebäck June 17, 1976

Isotope	pCi kg^{-1} dry	pCi kg^{-1} fresh
^{137}Cs	220 A	34 A
^{58}Co	8700	1330
^{54}Mn	880	134
^{65}Zn	300 B	50 B
^{60}Co	3200	490
Potassium	16.6 g kg^{-1} dry	

Table 8.5.2.3

Radionuclides in marine samples collected at Ringhals in 1976

pCi kg^{-1} fresh weight								
Sample and locations	Sampling date	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{95}Zr	^{137}Cs	^{40}K g kg^{-1}
Mytilus Edulis flesh N.E. of Ringhals	July 1 1976	-	310 A	190	300	-	22 A	1.6
Mytilus Edulis shells N.E. of Ringhals	-	-	-	49	-	-	24 A	0.5
Mytilus Edulis flesh at the outlet of Ringhals	-	-	811	1020	1250	-	38 A	0.68
Mytilus Edulis shells at the outlet of Ringhals	-	36 A	-	260	80 A	-	-	0.16
pCi kg^{-1} dry weight								
Fucus Vesicolosus Ringhals I	July 1 1976	480 A	2200 A	1900	490 B	-	260	17.5
Fucus Vesicolosus Ringhals II	-	1080	3400 A	4700	1200 A	-	270 A	13.2
Fucus Vesicolosus Ringhals III	-	1800	9100	13000	4600	-	160 B	13.9
Activities were corrected to sampling date.								

Table 8.5.2.4

Caesium-137 in bottom animals collected at Ringhals in July 1976

Species		Location	^{137}Cs pCi kg^{-1}	M.U.	Traces
Mytilus Edulis	Flesh	at the	13 B	5.5 B	^{95}Zr
" "	Shells	outlet	4 B	6.6 B	^{95}Zr, ^{60}Co
Mytilus Edulis	Flesh	N.E. of	B.D.L	B.D.L	^{60}Co
" "	Shells	the outlet	30 B	19 B	^{54}Mn
Cray fish	Total	at the outlet	240 A	60 A	
Snail	Flesh	at the outlet	43 B	22 B	

Table 8.5.2.5

Caesium-137 in fish collected at Ringhals in July 1976

Species		Position	^{137}Cs pCi kg^{-1}	M.U.
Dab	Meat	57°15'01"N 12°03'07"E	46	14.1
"	Total	-"- -"-	85	11.7
"	Total	-"- -"-	34	12.7
Whiting	Meat	-"- -"-	61	20
Cod	Meat	-"- -"-	58	19.1
Plaice	Meat	-"- -"-	29	8.7
Norway lobster	Meat	-"- -"-	155 A	36 A
Plaice	Meat	57°16'05"N 12°06'03"E	B.D.L	B.D.L
Dab	Meat	-"- -"-	19.1	5.8

8.5.3. Plutonium in 1975 Sediment Samples

Sediments from the 1975 program (cf. Risø Report No. 345[1], 8.5) were analysed for $^{239,240}Pu$. The integrated Pu deposit in the sediments (table 8.5.3) corresponded to the levels in soils

Table 8.5.3

$^{239,240}Pu$ mCi km^{-2}

in marine sediments collected in 1975 (cf. Risø Report 345, 8.5)

Depth	55°44'N 12°51'E	55°44'N 12°56'E	55°59'N 12°42'E	57°13'N 12°03'E	57°16'N 12°06'E	57°17'N 12°07'E	55°38'N 10°44'E	$\bar{x}$	±1 S.E.
	The Sound			The Cattegat			The Great Belt		
0-3 cm ("Pu/Cs")	0.53±0.03 (0.08)	0.50±0.02 (0.15)	0.21±0.02 (0.08)	0.77±0.19 (0.28)	0.39±0.03 (0.24)	0.44±0.06 (0.15)	0.31 (0.09)	0.45	0.07
3-6 cm ("Pu/Cs")	0.87±0.44 (0.16)	0.[illegible]3±0.12 (0.08)	0.41 (0.08)	0.89±0.24 (0.21)	0.66 (0.18)	0.56±0.10 (0.26)	0.52±0.02 (0.13)	0.59	0.09
6-9 cm ("Pu/Cs")	0.38±0.21 (0.12)	~ 0 -	0.50 (0.16)	0.30±0.11 (0.11)	0	0.19±0.03 (0.18)	0.28±0.01 (0.17)	0.23	0.07
9-12 cm ("Pu/Cs")	0.15±0.14 (0.08)	~ 0 -	0.52 (0.20)	0.03±0.01 (0.01)	-	~ 0	0.11 (0.14)	0.14	0.08
12-15 cm ("Pu/Cs")	0.07 (0.06)	0.03 -	0.24±0.03 (0.06)	0.00±0.01	-	-	0.02	0.07	0.04
Σ 0-15 cm	2.00	0.76	1.88	1.99	1.05	1.18	1.24	1.44	0.19

The error term is 1 S.E. determined from multiple (mostly triplicate) analyses.
"Pu/Cs": $^{239,240}Pu/^{137}Cs$

(tables 4.2.12-4.2.15), indicating that nearly all fall-out plutonium in shallow waters, such as the Danish, is found in the the sediments. The $^{239,240}Pu/^{137}Cs$ ratios showed that the vertical distributions of Pu and radiocaesium were similar, i.e. exponential with a half-depth of ~4 cm (cf. also the soil observations).

9. CONCLUSION

9.1. Risø Environmental Monitoring

No radioactive contamination of the environment originating from the operation of the research establishment was ascertained outside Risø in 1976. As in previous years, the variations in contamination level were independent of the distance of the sampling locations from Risø.

9.2. Nuclear-Weapon Debris in Air, Precipitation, Soil, Ground Water, and Surface Water

The mean content of ^{90}Sr in air collected in 1976 was 0.2 fCi ^{90}Sr m^{-3}, i.e. a quarter of the 1975 level. The average fall-out at the State experimental farms in 1976 was 0.10 mCi ^{90}Sr km^{-2} or a quarter of the 1975 figure, and the mean concentration of ^{90}Sr in rain water was 0.24 pCi ^{90}Sr l^{-1}.

By the end of 1976 the accumulated fall-out was approx. 53 mCi ^{90}Sr km^{-2}. The corresponding ^{137}Cs was estimated at 85 mCi km^{-2}.

In agreement with the greater precipitation in that part of the country, fall-out levels in Jutland were 15-25% higher than levels found in eastern Denmark.

The median level of ^{90}Sr in Danish ground water was 5 fCi ^{90}Sr l^{-1}.

9.3. Strontium-90 and Caesium-137 in the Human Diet

The mean level of ^{90}Sr in Danish milk was 3.4 S.U., and the mean content of ^{137}Cs was approx. 4.3 pCi ^{137}Cs l^{-1}.

The 1976 ^{90}Sr and ^{137}Cs levels were lower than the levels found in milk produced in 1975.

The ^{90}Sr mean content in grain from the 1976 harvest was 20 pCi ^{90}Sr kg^{-1}. The ^{137}Cs mean content in grain was 7 pCi

^{137}Cs kg^{-1}. The ^{90}Sr level in grain from the 1976 harvest was nearly equal to the level found in the 1975 harvest, and ^{137}Cs was half the 1975 level.

The mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1976 were 7 pCi ^{90}Sr kg^{-1} (17 S.U.) and 3 pCi ^{137}Cs kg^{-1}, respectively, and in fruits 1.0 pCi ^{90}Sr kg^{-1} and 1.9 pCi ^{137}Cs kg^{-1}; potatoes contained 1.7 pCi ^{90}Sr kg^{-1} and 2.2 pCi ^{137}Cs kg^{-1}.

The mean levels of ^{90}Sr and ^{137}Cs in total-diet samples collected in 1976 were 4.0 S.U., or 7 pCi ^{90}Sr day^{-1} and 10 pCi ^{137}Cs day^{-1}, respectively. From analyses of the individual diet components, the ^{90}Sr level in the Danish average diet was estimated to be 3.9 S.U. and the ^{137}Cs intake to be 11 pCi ^{137}Cs day^{-1}. The levels of ^{90}Sr and ^{137}Cs in the Danish total diet consumed in 1976 were lower than the 1975 levels.

Grain products contributed 36% and milk products 39% to the total ^{90}Sr intake; 34% of the ^{137}Cs in the diet originated from meat, 18% from grain products, and 18% from milk products.

Both ^{90}Sr and ^{137}Cs diet levels were on the average higher in Jutland than in eastern Denmark.

9.4. Strontium-90 and Caesium-137 in Humans

The ^{90}Sr mean content in human bone (vertebrae) collected in 1976 was approx. 1 S.U. in all age groups. The 1976 bone levels were lower than the 1975 levels.

The mean content of ^{137}Cs in the human body in 1976 was estimated from whole-body countings to be 1.3 nCi (10 pCi ^{137}Cs/g K), i.e. a little lower than the 1975 level.

9.5. Strontium-90 in Seawater

The mean content of ^{90}Sr in inner Danish surface water was approx. 0.7 pCi ^{90}Sr l^{-1} in 1976, and the ^{137}Cs mean level in Danish surface waters in 1976 was 0.8 pCi l^{-1}, i.e. nearly unchanged from 1975.

9.6. The γ-Background

The average γ-background measured with a NaI crystal at the State experimental farms in 1976 was 5.6 μR/h.

9.7. Radionuclides in the Marine Environment at Barsebäck and Ringhals

Sea plants (*Fucus*) and bivalves (*Mytilus*) collected at Barsebäck and Ringhals in 1976 showed low levels of corrosion products (^{54}Mn, ^{58}Co, ^{60}Co, ^{65}Zn) originating from the operation of the power plants. The levels did not constitute any health hazards.

9.8. Iodine-131 in Cows' Milk in 1976

The Chinese test explosion on 26 September 1976 resulted in a temporary contamination of cows' milk with ^{131}I. The estimated dose to an infant thyroid in Denmark from this contamination was 2 mrad.

9.9. Summary

The concentrations of long-lived fall-out nuclides in ground-level air and precipitation collected in 1976 were a quarter of the levels found in 1975.

In milk produced in 1975 the levels were approx. 3/4 of the 1975 levels. In grain from 1976 the ^{137}Cs levels were half of those found in 1975 while the ^{90}Sr concentrations were nearly unchanged.

The ^{90}Sr and ^{137}Cs levels in the total diet consumed in 1976 were approx. 2/3 of the 1975 levels.

The ^{90}Sr concentrations in human bone were lower in 1976 than in 1975.

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APPENDIX A

Calculated Fall-out in the Eight Zones in 1976

Zone	mm precipitation in 1976	mCi ^{90}Sr km^{-2} in 1976	Accumulated mCi ^{90}Sr km^{-2} by the end of 1976
I: N. Jutland II: E. Jutland III: W. Jutland IV: S. Jutland	566	0.107	57
V: Funen VI: Zealand VII: Lolland-Falster	421	0.086	45
VIII: Bornholm	532	0.109	-
Area-weighted mean	523	0.103	53

The amounts of precipitation were obtained from ref. 9. The ^{90}Sr deposition was estimated from 4.1 and appendix D. It was considered that the amount of precipitation collected by the rain bottles only were 0.82 times that measured by the Meteorological Institute.

APPENDIX B

Statistical information

Zone	Area in km² 15) 1971	Population in thousands 15) 1971	Annual milk production in mega-kg 14) 1971	Annual wheat production in mega-kg 13) 1972	Annual rye production in mega-kg 13) 1972	Annual potato production in mega-kg 13) 1972	Vegetable area in km² 13) 1972
I: N. Jutland	6,171	457	911	145	155	609	14
II: E. Jutland	7,561	841	1,258				
III: W. Jutland	12,104	661	926				
IV: S. Jutland	3,929	239	572				
V: Funen	3,486	434	393				
VI: Zealand	7,435	2,146*	395	448	71	100	73
VII: Lolland-Falster	1,795	125	68				
VIII: Bornholm	588	47	39				
Total	43,069	4,950	4,562	593	226	709	87

* 1,345,000 people were living in Greater Copenhagen and 801,000 in the remaining part of Zealand.

APPENDIX C

Our prediction models for grass, milk, vegetables and meat were revised in 1976. For these samples we used the data[1)] from 1962-75; for grain we used: 1959-74 (^{137}Cs: 1962-74), and for total diet: 1961-74. The terms in the models were similar to

Table C.1

A comparison between observed and predicted ^{90}Sr levels in the human food chain in Denmark in 1976

Sample and area	Observed	Predicted	Prediction equation	IEI
Grass from Zealand	25	19	$SU_i = 29\ d_i + 13\ d_{i-1} + 4.4\ A_{i-2(1)} + 0.19\ A_{i-2(28)}$	56
Milk from Jutland	4.2	4.7	$SU_i = 1.03\ d_i + 0.69\ d_{i-1} + 0.26\ A_{i-2(2)} + 0.059\ A_{i-2(28)}$	4.8
Milk from the Islands	2.2	2.6	$SU_i = 0.74\ d_i + 0.66 d_{i-1} + 0.14\ A_{i-2(6)}$	2.6
Rye from Jutland	65	51	$SU_i = 220\ d_{i(Jul-Aug)} + 0.15\ A_{i-1(5)} + 0.79\ A_{i-1(28)}$	70
Rye from the Islands	40	28	$SU_i = 170\ d_{i(Jul-Aug)} + 0.57\ A_{i-1(28)}$	51
Barley from Jutland	40	38	$SU_i = 164\ d_{i(Jul-Aug)} + 1.8\ A_{i-1(5)} + 0.17\ A_{i-1(28)}$	47
Barley from the Islands	17	19	$SU_i = 98\ d_{i(Jul-Aug)} + 0.83\ A_{i-1(5)} + 0.18\ A_{i-1(28)}$	30
Wheat from Jutland	64	58	$SU_i = 164\ d_{i(Jul-Aug)} + 1.7\ A_{i-1(5)} + 0.55\ A_{i-1(28)}$	62
Wheat from the Islands	25	32	$SU_i = 138\ d_{i(Jul-Aug)} + 0.44\ A_{i-1(5)} + 0.56\ A_{i-1(28)}$	49
Oats from Jutland	36	54	$SU_i = 74\ d_{i(Jul-Aug)} + 0.91\ A_{i-1(28)}$	49
Oats from the Islands	22	24	$SU_i = 60\ d_{i(Jul-Aug)} + 0.50\ A_{i-1(28)}$	30
Potatoes from Jutland	2.0	3.3	pCi ^{90}Sr kg^{-1} $= 0.13\ d_i + 0.08\ d_{i-1} + 0.05\ A_{i-2(1)} + 0.054\ A_{i-2(28)}$	2.4
Potatoes from the Islands	1.4	2.9	pCi ^{90}Sr kg^{-1} $= 0.16\ d_i + 0.07\ d_{i-1} + 0.061\ A_{i-2(28)}$	2.7
White cabbage from Jutland	6.7	11	pCi ^{90}Sr kg^{-1} $= 0.24\ d_i + 0.72\ d_{i-1} + 0.178\ A_{i-2(28)}$	8.1
White cabbage from the Islands	4.5	9	pCi ^{90}Sr kg^{-1} $= 0.56\ d_i + 0.01\ d_{i-1} + 0.08\ A_{i-2(3)} + 0.176\ A_{i-2(28)}$	8.0
Carrots from Jutland	2.6	18	pCi ^{90}Sr kg^{-1} (i) $= 0.16\ d_i + 1.1\ d_{i-1} + 0.29\ A_{i-2(28)}$	13
Carrots from the Islands	4.4	8	pCi ^{90}Sr kg^{-1} (i) $= 0.34\ d_i + 0.31\ A_{i-1(9)} + 0.016\ A_{i-1(28)}$	5
Total diet from Jutland	4.3	5.8	$SU_i = 1.49\ d_i + 0.95\ d_{i-1} + 0.097\ A_{i-2(5)} + 0.061\ A_{i-2(28)}$	5.6
Total diet from the Islands	4.0	5.1	$SU_i = 1.39\ d_i + 0.98\ d_{i-1} + 0.114\ A_{i-2(5)} + 0.094\ A_{i-2(28)}$	6.2
Newborn's bone	0.9	1.2	$SU_i = 0.073\ d_i + 0.14\ d_{i-1} + 0.022\ A_{i-2(28)}$	1.1
Human bone > 29 y	1.0	1.2	$SU_i = 0.067\ \frac{d_{i+(i-1)}}{2} + 0.036\ A_{i-2(5)} + 0.012\ A_{i-2(28)}$	0.8

those used in previous years (cf. Risø Report No. 345, Appendix C[1]), but in the case of ^{137}Cs the fall-out rate: $\underline{d}'$ and the accumulated fall-out: $\underline{A}'$ refer to ^{137}Cs fall-out instead of as earlier to ^{90}Sr fall-out; $d' = 1.6 \cdot d$ and $A' = 1.6 \cdot A$, as the $^{137}Cs/^{90}Sr$ in fall-out is 1.6[21]. The IEI (infinite time exposure integral) for ^{137}Cs is now based on ^{137}Cs fall-out and is thus 1.6 times less than the earlier values.

In Appendix D values are shown for the ^{90}Sr fall-out rates (d_i) and some of the accumulated ^{90}Sr fall-out (A_i) used in our calculations of prediction models.

The predicted values in 1976 for ^{90}Sr were in general higher, whereas the ^{137}Cs values were lower than those observed.

Table C 2

A comparison between observed and predicted ^{137}Cs levels in the human food chain in Denmark in 1976

Sample and area	Observed	Predicted	Equation used for the prediction	IEI'
Milk from Jutland	3.4	1.3	$pCi\ ^{137}Cs\ (g\ K)^{-1}_{(i)} = 2.7\ d'_i + 0.77\ d'_{i-1} + 0.20\ d'_{i-2}$	3.6
Milk from the Islands	1.6	1.1	$pCi\ ^{137}Cs\ (g\ K)^{-1}_{(i)} = 1.76\ d'_i + 0.66\ d'_{i-1} + 0.022\ A'_{i-2(5)}$	2.6
Rye from Jutland	16	4.2	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 82\ d'_{i\,(May-Aug)}$	27
Rye from the Islands	6.5	4.0	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 78\ d'_{i\,(May-Aug)}$	26
Barley from Jutland	6.8	3.2	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 63\ d'_{i\,(May-Aug)}$	21
Barley from the Islands	0.9	2.7	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 53\ d'_{i\,(May-Aug)}$	18
Wheat from Jutland	7.0	3.6	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 71\ d'_{i\,(May-Aug)}$	24
Wheat from the Islands	3.0	2.3	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 45\ d'_{i\,(May-Aug)}$	15
Oats from Jutland	13	2.7	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 52\ d'_{i\,(May-Aug)}$	17
Oats from the Islands	6.5	2.5	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 49\ d'_{i\,(May-Aug)}$	16
Potatoes from Jutland	3.5	0.6	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 3.5\ d'_i$	3.5
Potatoes from the Islands	0.9	0.5	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 3.3\ d'_i$	3.3
White cabbage	2.1	1.8	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 0.81\ d'_i + 0.043\ A'_{i-1(8)}$	1.3
Carrots	0.4	0.6	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 1.49\ d'_i + 0.092\ A'_{i-1(2)}$	1.8
Pork	22	15	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 16.6\ d'_i + 16.4\ d'_{i-1} + 1.17\ A'_{i-2(1)}$	35
Beef	32	9	$pCi\ ^{137}Cs\ kg^{-1}_{(i)} = 25\ d'_i + 0.2\ d'_{i-1} + 1.17\ A'_{i-2(2)}$	29
Total diet from Jutland	2.6	2.4	$pCi\ ^{137}Cs\ (g\ K)^{-1} = 2.4\ d'_i + 1.0\ d'_{(i-1)+(i-2)}$	4.4
Total diet from the Islands	2.5	1.8	$pCi\ ^{137}Cs\ (g\ K)^{-1} = 2.2\ d'_i + 0.93\ d'_{(i-1)+(i-2)}$	4.1
Whole body from the Islands	9.5	15	$pCi\ ^{137}Cs\ (g\ K)^{-1} = 2.4\ d'_i + 4.2\ d'_{(i-1)+(i-2)} + 0.10\ A'_{i-3(30)}$	15

APPENDIX D

$\underline{d_i}$: Annual fall-out rate in mCi ^{90}Sr $km^{-2}y^{-1}$.

$\underline{A_{i(5)}}$: Accumulated fall-out by the end of the year (i) assuming an effective half-life of ^{90}Sr of 5 y.
Unit: mCi ^{90}Sr km^{-2}.

$\underline{A_{i(15)} \text{ and } A_{i(27.7)}}$:

Accumulated fall-out by the end of the year (i) assuming effective half-lives of ^{90}Sr of 15 y and 27.7 y, respectively.
Unit: mCi ^{90}Sr km^{-2}.

$\underline{d_{i(May-Aug.)} \text{ and } d_{i(July-Aug.)}}$:

The fall-out rates in the periods:
May-Aug. and July-Aug., respectively.
Unit: mCi ^{90}Sr km^{-2} $period^{-1}$.

The fall-out rate (d_i) was based on precipitation data collected for all Denmark in the period 1962-1976 (cf. table 4.1.1[1)]). Before 1962 the levels in the tables were estimated from the HASL data for New York (HASL Appendix 291, 1975) considering that the mean ratio between ^{90}Sr fall-out in Denmark and New York was 0.7 in the period 1962-1974.

The $d_{i(May-Aug.)}$ and $d_{i(July-Aug.)}$ values were also obtained from table 4.1.1[1)] for the period 1962-1976. For the years 1959-1961 the values were calculated from data obtained from ^{90}Sr analysis of air (1959) and precipitation samples (1962 and 1961) collected at Risø (cf. ref. 17). Before 1959, the values were estimated from the corresponding d_i values assuming that the ratios $d_{i(May-Aug.)}/d_i$ and $d_{i(July-Aug.)}/d_i$ were constant in time and equal to the means found for the period 1962-1974, which were 0.54 (1 S.D.: 0.09) and 0.24 (1 S.D.: 0.06), respectively.

APPENDIX D

Fallout rates and accumulated fallout (mCi ^{90}Sr km^{-2}) in Denmark 1950-1976

	Denmark				Jutland				Islands				Denmark		Jutland		Islands	
	d_i	$A_{i(5)}$	$A_{i(15)}$	$A_{i(27.7)}$	d_i	$A_{i(5)}$	$A_{i(15)}$	$A_{i(27.7)}$	d_i	$A_{i(5)}$	$A_{i(15)}$	$A_{i(27.7)}$	$d_{i(\text{May-Aug.})}$	$d_{i(\text{July-Aug.})}$	$d_{i(\text{May-Aug.})}$	$d_{i(\text{July-Aug.})}$	$d_{i(\text{May-Aug.})}$	$d_{i(\text{July-Aug.})}$
1950	0.021	0.018	0.020	0.020	0.022	0.019	0.021	0.021	0.020	0.017	0.019	0.020	0.01	0.01	0.01	0.01	0.01	0.01
1951	0.101	0.104	0.116	0.118	0.114	0.116	0.129	0.132	0.088	0.092	0.102	0.105	0.05	0.02	0.06	0.03	0.05	0.02
1952	0.198	0.263	0.299	0.309	0.224	0.296	0.337	0.347	0.172	0.230	0.262	0.270	0.11	0.05	0.12	0.05	0.09	0.04
1953	0.500	0.664	0.763	0.789	0.566	0.751	0.862	0.891	0.434	0.578	0.665	0.687	0.27	0.12	0.31	0.14	0.23	0.10
1954	1.901	2.233	2.544	2.623	2.152	2.526	2.878	2.967	1.650	1.939	2.210	2.279	1.03	0.46	1.16	0.52	0.89	0.40
1955	2.501	4.121	4.817	4.997	2.831	4.664	5.451	5.655	2.171	3.578	4.183	4.340	1.35	0.60	1.53	0.68	1.17	0.52
1956	3.101	6.287	7.560	7.898	3.510	7.116	8.557	8.939	2.692	5.458	6.564	6.858	1.67	0.74	1.90	0.84	1.45	0.65
1957	3.101	8.173	10.180	10.728	3.510	9.251	11.522	12.142	2.692	7.095	8.838	9.313	1.67	0.74	1.90	0.84	1.45	0.65
1958	4.302	10.860	13.828	14.658	4.869	12.292	15.651	16.591	3.734	9.427	12.004	12.725	2.32	1.03	2.63	1.17	2.02	0.90
1959	6.102	14.766	19.030	20.247	6.908	16.715	21.540	22.918	5.297	12.817	16.519	17.576	2.50	0.68	2.76	0.75	2.24	0.61
1960	1.140	13.847	19.259	20.859	1.291	15.675	21.800	23.610	0.990	12.020	16.718	18.107	0.47	0.31	0.52	0.34	0.42	0.28
1961	1.481	13.344	19.803	21.787	1.676	15.105	22.416	24.661	1.285	11.583	17.190	18.913	0.66	0.47	0.73	0.52	0.59	0.42
1962	7.428	18.083	26.001	28.493	7.976	20.093	29.019	31.830	6.880	16.073	22.983	25.155	4.223	1.857	4.566	2.052	3.880	1.662
1963	16.695	30.276	40.768	44.071	18.453	33.556	45.329	49.041	14.937	26.996	36.208	39.101	9.965	5.629	10.753	5.932	9.177	5.327
1964	10.412	35.421	48.869	53.136	11.685	39.384	54.439	59.225	9.139	31.457	43.299	47.048	6.235	2.568	7.170	2.910	5.299	2.226
1965	3.954	34.277	50.437	55.679	4.204	37.946	55.994	61.861	3.704	30.609	44.880	49.497	2.029	0.850	2.094	0.852	1.964	0.848
1966	2.145	31.707	50.207	56.395	2.166	34.919	55.534	62.445	2.124	28.495	44.881	50.345	1.049	0.418	0.984	0.496	1.114	0.340
1967	1.047	28.514	48.940	56.023	1.176	31.423	54.149	62.048	0.918	25.606	43.731	49.997	0.367	0.141	0.380	0.134	0.354	0.148
1968	1.403	26.044	48.069	56.006	1.568	28.720	53.201	62.045	1.237	23.368	42.938	49.968	0.848	0.426	0.910	0.460	0.786	0.392
1969	1.035	23.574	46.887	55.632	1.241	26.083	51.983	61.721	0.829	21.065	41.791	49.542	0.614	0.276	0.723	0.319	0.505	0.233
1970	1.647	21.956	46.342	55.863	1.993	24.442	51.539	62.140	1.301	19.471	41.146	49.586	0.908	0.547	1.076	0.632	0.740	0.462
1971	1.506	20.425	45.688	55.951	1.726	22.780	50.860	62.288	1.286	18.070	40.515	49.615	0.992	0.405	1.154	0.516	0.830	0.294
1972	0.435	18.160	44.040	54.993	0.457	20.229	49.000	61.194	0.413	16.090	39.080	48.792	0.253	0.084	0.262	0.084	0.244	0.084
1973	0.192	15.976	42.235	53.821	0.215	17.798	46.993	59.891	0.168	14.153	37.476	47.750	0.075	0.033	0.093	0.039	0.057	0.027
1974	0.710	14.526	41.006	53.183	0.779	16.172	45.615	59.171	0.643	12.881	36.398	47.197	0.421	0.190	0.463	0.219	0.378	0.162
1975	0.414	13.006	39.550	52.272	0.452	14.472	43.987	58.150	0.376	11.541	35.113	46.397	0.159	0.075	0.179	0.091	0.141	0.060
1976	0.103	11.413	37.862	51.082	0.116	12.699	12.110	56.826	0.090	10.126	33.614	45.339	0.032	0.010	0.032	0.011	0.032	0.009

APPENDIX E

Plutonium-239 and -240 in grain samples from 1963 and 1965

The maximum concentrations of long-lived fall-out nuclides occurred in the first half of the sixties. The present study was carried out to get an impression of the possible maximum plutonium concentrations from fall-out to be found in Danish diet components. Grain was selected because grain products have been the main contributors to radioactive contamination of the Danish diet during periods with high fall-out rates.

In 1963 the mean concentrations in rye and wheat were 1.43 and 0.35 μCi ^{239,240}Pu kg^{-1}, respectively. In 1965 these levels had decreased by a factor of 5-6, corresponding to the ratio between the ^{90}Sr fall-out in the summer months of the two years.

Appendix E.1

Plutonium-239,240 in grain from the state experimental farms in 1963

	Rye		Barley		Wheat		Oats
	Winter	Spring	Spring	Winter	Winter	Spring	Spring
Tylstrup	*1.48±0.10		2.6±0.1				1.97±0.41
Studsgård			1.70	3.1			0.83
Ødum	*0.97±0.05		1.47		0.22±0.10		0.99
Askov	1.14		1.64		0.183	0.54	2.0±0.1
St. Jyndevad			1.34				0.66
Blangstedgård			2.1		0.24		1.27
Tystofte	2.1		0.71			0.34	0.74
Virumgård	1.46		2.0				2.9
Abed			1.13		0.49	0.47	0.99
Åkirkeby			1.38				0.78
Mean	1.43		1.61	3.1	0.28	0.45	1.31

*triple determinations

Appendix E.2

Plutonium-239,240 in grain from the state experimental farms in 1965

	Rye		Barley		Wheat		Oats
	Winter	Spring	Spring	Winter	Winter	Spring	Spring
Tylstrup	0.145		0.21		0.062	0.095	0.122
Studsgård	0.29	0.132	0.46		0.23	0.112	0.149
Ødum	0.157		0.41		0.070	0.047	0.109
Askov	0.48		0.72		0.110		0.146
St. Jyndevad	0.39		0.48		0.084		0.30
Blangstedgård			0.30		0.046		0.21
Tystofte	0.134		0.28		B.D.L	0.043	0.21
Virumgård	0.071±0.011		0.31		0.0116	0.086	0.25
Åbed			0.41		0.0170	0.092	0.34
Åkirkeby			0.37		0.070	0.065	0.27
Ledreborg			0.29		B.D.L	0.032	0.104
Mean	0.24	0.132	0.39		0.064	0.072	0.20

Appendix E.3

Anova of ln pCi ^{239,240}Pu kg^{-1} grain from 1963 and 1965

Effect	Source of variation	SSD	f	s^2	v^2	P
Main	years (y)	59.895	1	59.895	236.92	> 99.95%
"	species (s)	38.555	3	12.852	50.836	> 99.95%
"	location (l)	3.910	10	0.391	1.547	$\sim$ 85.2%
Interaction	y x s	0.636	3	0.212	0.902	$\sim$ 53.9%
"	s x l	4.781	26	0.184	0.782	$\sim$ 27.9%
"	y x l	3.253	9	0.361	1.537	$\sim$ 78.7%
"	y x s x l	3.998	17	0.235	0.793	$\sim$ 31.6%
Remainder		6.528	22	0.297		

It is remarkable that the interspecific variation is more pronounced for plutonium than for other radionuclides (^{90}Sr, ^{137}Cs, ^{54}Mn) and that the concentration order is barley > oats $\sim$ rye > wheat, while the order of the direct contamination for other radionuclides[1)] is rye > barley > wheat $\sim$ oats.

A discussion of these observations will appear in forthcoming publication.

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